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HENRY HORNER, Governor
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 39

ILLINOIS MINERAL INDUSTRY IN 1934

A Preliminary Statistical Summary and Economic Review

BY

W. H. VOSKUIL and ALMA R. SWEENY

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ILLINOIS MINERAL INDUSTRY IN 1934

A PRELIMINARY STATISTICAL SUMMARY AND ECONOMIC REVIEW

Walter H. Voskuil and Alma R. Sweeny

THIS REPORT, which presents the fundamental statistics in the distribution and consumption of the major mineral products of the State, is made possible through the cooperation of the United States Bureau of Mines and the United States Bureau of the Census, through the active collection and publication of coal statistics by the Illinois State Department of Mines and Minerals, and through the generous cooperation of the mineral producers of the State in complying with requests for information.

The quantity and value of mineral output in Illinois in 1933 and 1934 is shown in Table 1.

The mineral industry in Illinois is slowly rising from the depths of the depression and is responding to the gradually increasing industrial activity. Coal production has shown an increase, the oil industry has enjoyed higher prices than in the previous year and the resumption of building operations is bringing about an increase in the shipments of clay products. Improvements in the steel industry have favorably affected the fluorspar industry in Pope and Hardin counties.

The search for new and improved uses for minerals has resulted in the establishment of plants for the manufacture of rock wool and is contemplating improvements in the preparation of coal. Improved methods of oil recovery have met with favorable results and an increase in oil recovery by an extension of these methods may reasonably be expected.

Table 1.—Preliminary Summary of Production and Value of Illinois Minerals, 1933-1934

Product	1933		1934	
	Tons	Value	Tons	Value
Coal	37,413,145	$54,578,000	35,023,844	$64,238,000
Pig iron	1,269,940	20,063,481		
Clay products		4,145,033		945,199
Coke	1,501,020	7,379,561	1,649,907	9,071,800
Cement (barrels) Portland	4,193,048	4,607,335	3,908,107	5,498,568
Sand and gravel (total)	6,107,829	3,370,039	6,174,202	3,373,690
Structural sand	724,368	325,852	606,354	302,558
Paving and road-making sand	1,109,710	503,952	1,014,805	419,832
Glass sand	402,240	403,578	448,804	449,832
Molding sand	223,241	209,272	347,078	320,242
Railroad ballast sand	132,720	46,802	161,348	65,774
Cutting, grinding and blast sand	99,135	275,294	107,366	334,953
Engine sand	44,503	22,048	39,000	21,546
Fire or furnace sand	([a])	([a])	([a])	([a])
Other sands	181,229	117,895	123,129	125,675
Structural gravel	576,309	312,134	602,212	315,864
Paving and road-making gravel	2,358,033	1,048,160	2,265,690	872,444
Railroad ballast gravel	383,290	144,809	291,166	62,193
Other gravel	47,892	20,610	167,250	82,777
Petroleum (barrels)	4,244,000	3,690,000	4,479,000	4,490,000
Limestone (total)	2,397,400	1,709,250	3,901,560	2,881,651
Road metal and concrete	1,759,490	1,191,538	2,667,242	1,963,405
Flux	135,190	76,394	257,650	149,225
Railroad ballast	126,220	85,447	228,517	150,263
Rip-rap	113,830	116,584	192,360	207,751
Rubble	([a])	([a])	68,450	47,690
Agriculture	221,250	161,122	448,810	291,761
Other uses	41,420	78,165	38,531	71,556
Mineral paints, zinc and lead pigments	12,539	1,268,853		
Natural gasoline (gallons)	3,673,000	194,000	3,810,378	
Natural gas (M. cu. ft.)	1,631,000	951,000		
Lime (total)	81,888	575,862	86,679	665,359
Building	11,799	93,919	14,113	120,079
Tanneries	([a])	([a])	([a])	([a])
Metallurgy	([a])	([a])	([a])	([a])
Paper mills	([a])	([a])	3,121	20,427
Other uses	70,089	481,945	69,445	514,853
Fluorspar	36,075	543,060	33,234	567,396
Quartz (silica)	52,230	273,526	50,748	285,849
Clay (raw)	72,447	197,532	69,921	160,537
Tripoli	8,757	149,979	7,417	119,418
Lead	240	17,760	40	3,160
Sandstone			3,900	5,761
Zinc				
Total		$74,837,452		$98,268,729

---

[a] Included in other uses.

COAL

Review of production.—Coal output in Illinois in 1934 kept pace with the national increase of production over 1933. A preliminary report from the Bureau of Mines reports a total output of coal in the United States of 358,395,000 tons of which Illinois produced 40,905,000 tons, or 11.4 per cent. Final figures of coal production for 1933 and preliminary figures for 1934 are given in Table 2.

Table 2.—Summary of Coal Production in 1933 and 1934
(In thousands of tons)

Year	United States	Illinois	Illinois per cent of total
1933	333,631	37,413	11.2
1934	358,395	40,905	11.4

The production of shipping mines in Illinois, by months, as shown in the reports of the Illinois State Department of Mines and Minerals, is given in Table 3.

In view of the attempts to stabilize the production of coal by legislation among the several mining districts of the United States, it may be of interest to analyze the trend of production, seasonal fluctuations and changes in employment in the Illinois coal industry. The principal competing fields of the Illinois coal industry among the Appalachian fields are New River-Winding Gulf, Pocahontas and Tug River in southern West Virginia and northeast Kentucky, and McRoberts in eastern Kentucky, and frequent comparisons will be made with the trends in these fields.

TABLE 3.—BITUMINOUS COAL PRODUCTION BY SHIPPING MINES IN

County	January	February	March	April	May
Christian	374,167	349,883	331,161	221,986	239,099
Clinton	39,785	43,476	41,813	6,447	4,142
Franklin	787,405	733,572	811,116	431,576	367,836
Fulton	130,614	121,148	144,880	95,571	86,063
Henry	59,676	55,551	68,035	47,637	....
Jackson	139,075	125,812	140,951	82,212	106,786
La Salle	20,805	19,009	20,478	12,725	....
Macoupin	336,718	321,343	355,946	228,152	202,900
Madison	149,642	168,704	170,232	86,971	70,574
Marion	36,439	34,465	40,729	....	....
Montgomery	73,287	71,835	83,197	24,204	25,088
Peoria	135,364	126,462	137,547	93,630	82,799
Perry	290,527	294,418	291,499	213,406	192,125
Randolph	53,797	47,491	54,268	31,032	32,676
Saline	316,756	311,029	358,269	87,497	149,321
Sangamon	293,885	241,092	277,285	160,076	103,916
St. Clair	275,212	271,233	280,023	85,814	71,506
Tazewell	20,586	20,375	21,071	10,366	....
Vermilion	160,666	174,437	191,779	140,468	112,187
Washington	28,682	27,021	30,187	15,008	16,563
Williamson	191,694	185,914	210,925	128,675	86,531
Woodford	15,208	13,162	14,088	3,162	....
Other Counties	175,882	160,385	161,771	126,188	158,700
Total	4,105,872	3,917,817	4,237,250	2,332,803	2,108,812
Strip Mines	564,375	531,657	572,871	447,072	340,207
Shaft Mines	3,541,497	3,386,160	3,664,379	1,885,731	1,768,605

[a] Compiled from Monthly Reports of the Illinois State Department of Mines and Minerals.

ILLINOIS BY COUNTIES AND MONTHS FOR 1934 [a] (IN NET TONS)

June	July	August	September	October	November	December	Total
255,145	248,741	342,152	351,681	406,827	348,149	391,709	3,860,700
10,000	9,530	10,199	21,284	20,923	29,685	45,971	283,255
454,361	459,720	595,798	751,974	763,576	684,099	922,087	7,763,120
88,866	97,027	106,176	109,664	147,672	158,488	180,353	1,466,522
....	....	....	38,266	48,867	41,797	41,511	401,340
126,532	117,092	143,169	125,726	127,182	124,019	119,589	1,478,145
....	....	....	12,766	18,003	21,731	24,775	150,292
163,998	223,685	261,827	269,767	312,272	305,686	329,047	3,311,341
64,737	60,538	97,724	133,650	149,033	157,574	190,885	1,500,264
....	....	19,489	26,168	27,809	31,756	39,799	256,654
23,713	26,274	25,354	38,101	42,574	45,971	64,652	544,250
67,147	....	84,065	89,212	123,284	104,729	135,331	1,179,570
193,265	201,310	206,134	229,781	264,601	238,467	357,697	2,973,230
26,491	22,389	20,228	30,264	36,201	36,112	48,839	439,788
108,026	134,610	202,079	201,905	243,690	234,721	353,036	2,700,939
82,848	122,346	113,903	168,125	173,904	181,660	275,804	2,194,844
64,238	69,011	115,324	173,087	186,355	201,125	259,707	2,052,635
....	....	15,613	22,519	20,332	22,014	27,973	180,849
116,687	94,094	110,693	101,230	134,718	155,537	175,583	1,668,079
16,367	20,489	28,436	23,556	32,343	29,976	40,312	308,940
91,811	79,306	102,656	176,495	190,510	195,157	232,102	1,871,776
....	....	....	10,853	12,099	12,960	14,465	95,997
142,415	225,010	151,676	125,098	143,625	149,091	160,487	1,880,328
2,096,647	2,211,172	2,752,695	3,231,172	3,626,400	3,510,504	4,431,714	38,562,858
365,486	415,860	424,046	443,300	536,298	514,969	621,061	5,777,202
1,731,161	1,795,312	2,328,649	2,787,872	3,090,102	2,795,535	3,810,653	32,785,656

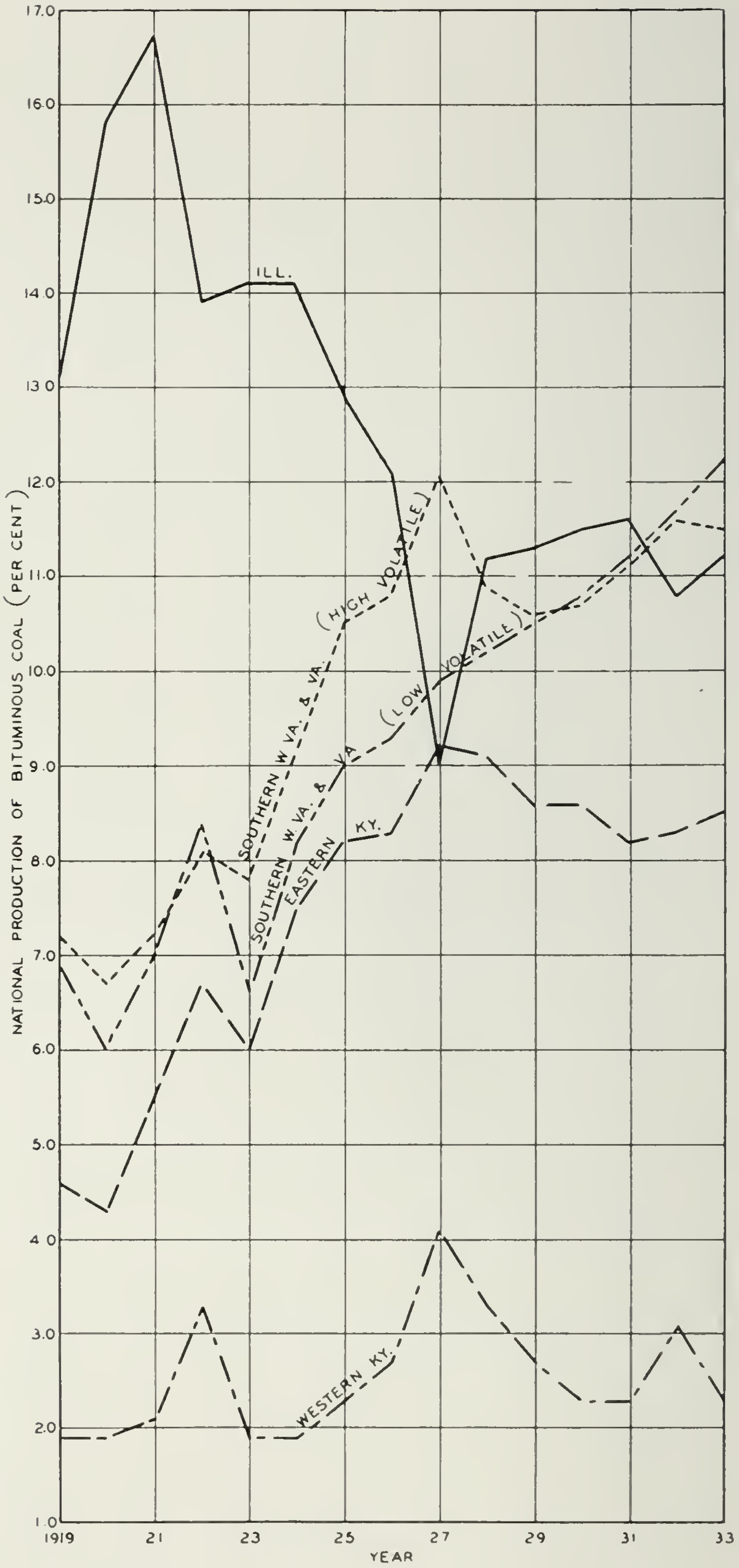

Fig. 1.—Percentage of Illinois' Share of National Production of Bituminous Coal Since 1918, as Compared With Three Competing Areas.

The portion of the national coal market from 1919 to 1934 shared by Illinois and some of the more important competitive fields supplying the Illinois coal market area is shown in figure 1. Increases are particularly noticeable in the high and low volatile fields of West Virginia and eastern Kentucky.

The shifts in percentages shown are of especial significance in the light of proposed legislation for the attempted stabilization of the coal industry.

The decline in Illinois production and the concurrent rise in output in the high and low volatile fields of West Virginia and the fields of eastern Kentucky, is, to a certain extent, the result of a differential in the wage scales in favor of the Appalachian fields. During that period, eastern Kentucky increased its proportion of the national output from 4.8 per cent to 8.5 per cent, the low volatile district of southern West Virginia and Virginia increased from 6.9 per cent to 12.2 per cent and the high volatile district increased from 7.2 per cent to 11.5 per cent. The average contributions of these three fields in the fifteen-year period from 1919 to 1933 are 7.41 per cent, 9.02 per cent, and 9.65 per cent, respectively.

The relative changes in the position of Illinois and its principal competing fields are summarized in Table 4.

TABLE 4.—PERCENTAGE OF TOTAL BITUMINOUS COAL PRODUCTION IN ILLINOIS AND COMPETING FIELDS, IN SPECIFIED YEARS

Field	1919	1933	1919–1933 Average
Illinois	13.0	11.2	12.67
Eastern Kentucky	4.6	8.5	7.41
Low volatile of southern West Virginia and Virginia	6.9	12.2	9.02
High volatile of southern West Virginia and Virginia	7.2	11.5	9.65

Long-time trends in coal output and employment.—Figure 2 shows the production of coal, the number of men employed, the number of days worked per year, and the output per man per day in the coal mining industry of Illinois from 1900 to 1933. Decline in coal production from the high peaks of 1916 and 1920 was to be expected as a result of the cessation of war time demands. Decline in the number of men employed follows, more or less, with the falling output during the post-war period. Even more serious than the lessened output and number of men employed is the decrease in the number of days worked per year. The annual income of the miner is a product of his daily wage and his annual working opportunity. The decline in working opportunity is partly the result of increasing summer volume of lake cargo coal from the Appalachian fields, and partly in increased output per man per day. In thirty years, the latter has increased from 3 tons per day to more than 6 tons.

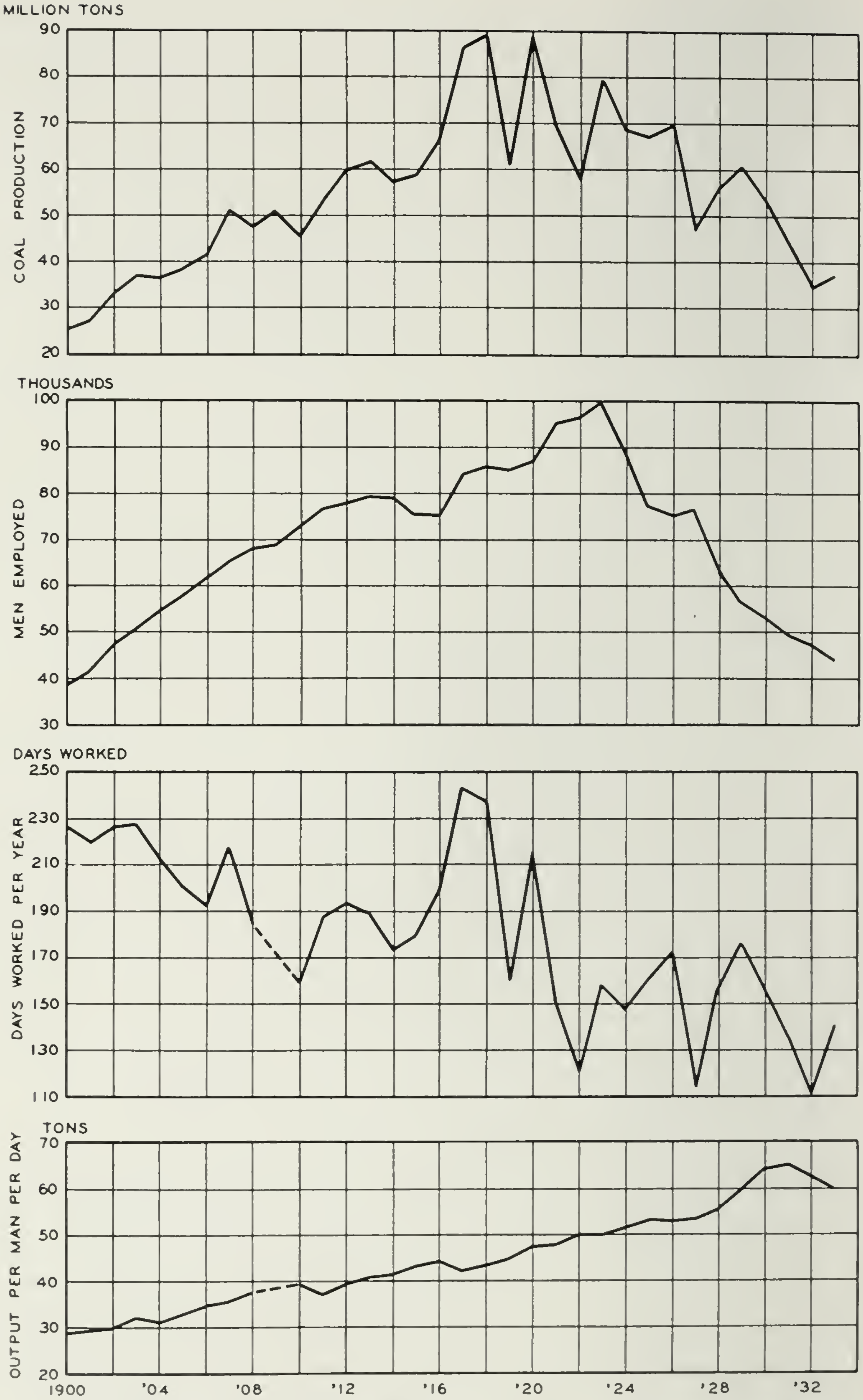

Fig. 2.—Elements of Long-Time Trends of Production and Employment.

Seasonal trends in coal production.—A contributing factor toward limiting the working opportunity of the coal miner in Illinois is the seasonality of coal demand. Figure 3 shows the average output of coal, by months, in Illinois, for the period 1917-1934 and fluctuations in employment for the same period. This seasonal fluctuation in the coal industry is particularly disadvantageous to the Illinois industry as compared with rival fields in West Virginia and eastern Kentucky, because of the influence of lake cargo coal upon the latter fields. This lake trade affords a summer outlet for coal produced in eastern fields. The lakes are closed to navigation because of weather conditions from some time in December until the following April and all coal moved by this route must be moved in the remaining part of the year. In that period the markets for coal reached by all-rail haul from the eastern fields are least active,

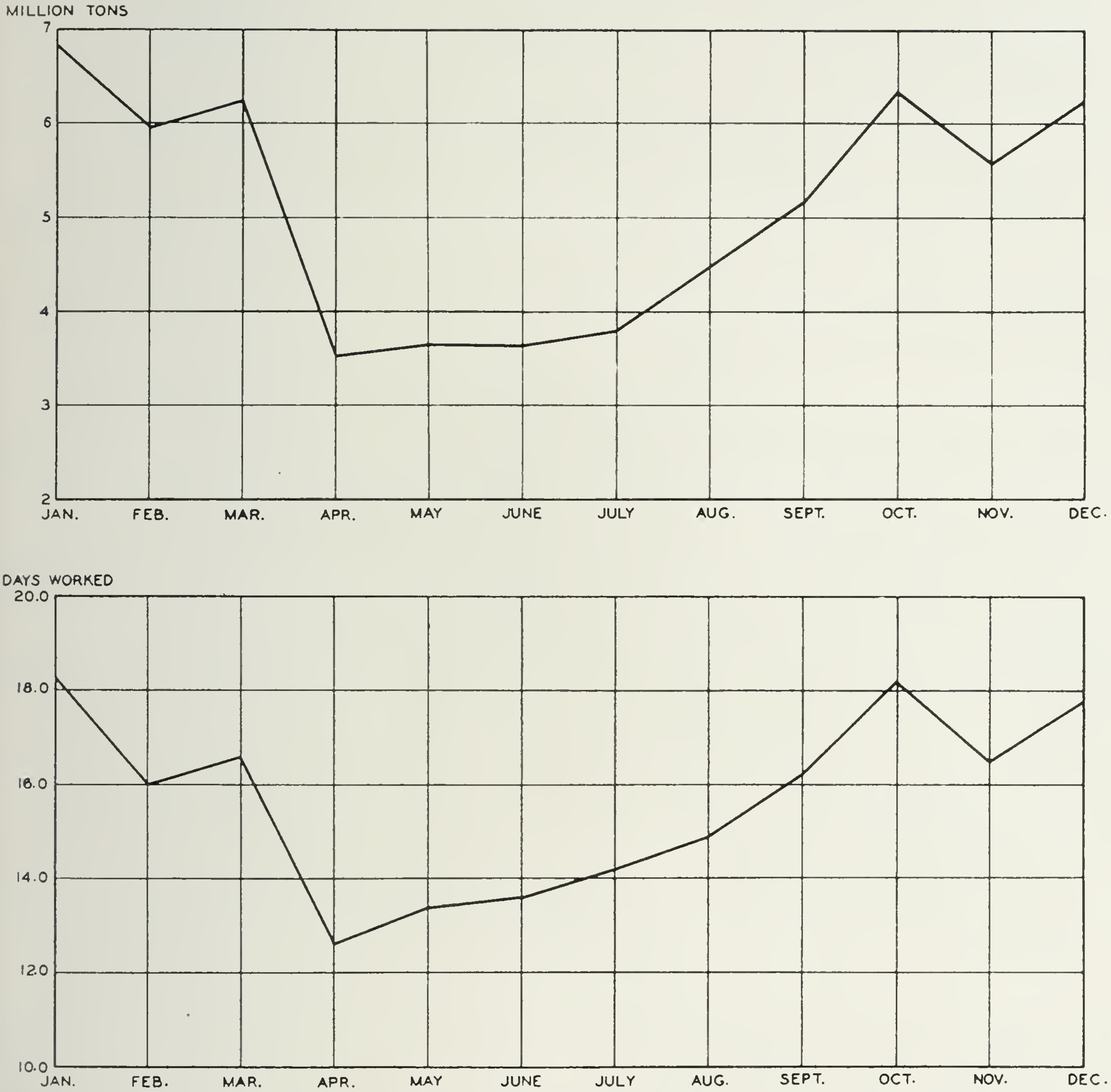

Fig. 3.—Average Production of Coal for the Period 1917 to 1934 Inclusive, by Months, and Fluctuations in Employment for the Same Period.

and the opportunity to maintain operation of the mines during the summer is welcomed by the producers. So well recognized is this fact that the larger producers in the eastern fields tributary to the lakes maintain organizations at the head of the lake with docks and equipment, and during periods when the market near at hand is dull these producers ship coal to the head of the lakes where it is stored on the docks awaiting the winter market. The producer is then enabled to operate his mines more continuously. The discrepancy in working opportunity between Illinois and Appalachian fields, as shown by Table 5, bears out this analysis.

TABLE 5.—TOTAL NUMBER OF DAYS WORKED PER YEAR IN COAL MINING IN ILLINOIS, WEST VIRGINIA, KENTUCKY, AND PENNSYLVANIA [a]

Year	Illinois	West Virginia	Kentucky	Pennsylvania
1917	243	225	214	261
1918	238	238	230	269
1919	160	200	189	218
1920	213	198	182	244
1921	152	149	152	151
1922	120	143	140	154
1923	158	169	152	213
1924	148	182	174	180
1925	161	225	206	200
1926	172	247	230	224
1927	114	235	237	203
1928	156	223	212	218
1929	177	247	222	230
1930	156	204	187	198
1931	136	176	159	160
1932	112	168	155	146

[a] U. S. Bureau of Mines, Mineral Resources of the United States, Chapters on Coal.

The pronounced seasonality in coal production in Illinois not only limits the annual working opportunity for miners but tends to raise the per ton cost of production.

Distribution of coal in the Illinois coal market area.—Table 6 gives a summary of all-rail revenue coal (exclusive of railway fuel) shipped into the Illinois coal market area by market districts since 1932. Shipments of Illinois coal have gained since the low period of 1932. Of interest is the substantial gain in coal shipments into the Wisconsin market area. The invasion of natural gas has curtailed shipments sharply in the Kansas City market in 1933 and 1934 as compared with 1932.

While the all-rail shipments of coal during these three years show a slight recovery of the market for Illinois producers, the movement of coal over the Great Lakes into the Illinois coal market area continues at a high level.

Table 7 shows total shipments of all-rail revenue coal into the Illinois territory and the percentage of shipments from Illinois for the years 1932, 1933, and 1934.

Tables 8 and 9 show the bituminous coal shipments to American ports on Lake Superior and Lake Michigan from 1929 to 1934 and the receipts of coal at Upper Lake Docks from 1931 to 1934.

In Tables 10 to 13 are shown the shipments of bituminous coal and anthracite to principal ports on the western shore of Lake Michigan and to the Duluth-Superior port on Lake Superior since 1920. The interesting feature of these shipments is the downward trend of anthracite. Before the World War, anthracite occupied an important position in the domestic fuel markets of the Lake Docks territory. The subsequent drastic increase in price of anthracite has stimulated the substitution of other types of prepared domestic fuels, notably coke, fuel oil, and briquets.

Table 6.—Origin and Destination of Revenue Railroad Shipments From Illinois, Railroad

From	Chicago	Illinois, other	Milwaukee	Wisconsin, other	Council Bluffs
1932					
Western Pennsylvania	325	86	126	226	....
Altoona, Somerset-Meyersdale and Cumberland-Piedmont	12,417	3,813	242	1,814	588
Fairmont (W. Va.)	14,840	1,670	1,003	2,386	....
Northern and Eastern Ohio	1,980	....	150	770	....
Southern Ohio	2,596	142	....	50	....
Kanawha, (W. Va.) Logan and Kenova-Thacker (W. Va.-E. Ky.)	825,727	178,434	4,206	70,537	3,621
New River-Winding Gulf and Pocahontas-Tug River (W. Va.)	5,942,825	375,706	158,848	535,263	202
Northeast Kentucky and McRoberts	491,950	220,571	1,479	70,290	288
Virginia	39,361	13,214	2,422	28,945	....
Harlan and Hazard (E. Ky.)	1,030,422	514,807	4,469	60,264	1,838
Ex-River Coal	626	1,101	....	....	....
Northern Illinois	603,657	1,244,808	....	14,632	238
Central and Southern Illinois	3,862,441	5,454,889	11,297	321,495	94,237
Indiana	2,720,859	1,143,782	18,689	286,759	2,340
Western Kentucky	1,004,353	1,003,425	4,757	260,201	18,863
Total	16,554,379	10,156,448	207,688	1,653,632	122,305
1933					
Western Pennsylvania	3,964	50	....	839	32
Altoona, Somerset-Meyersdale and Cumberland-Piedmont	29,667	5,324	383	2,040	561
Fairmont (W. Va.)	17,928	1,671	306	1,982	....
Northern and Eastern Ohio	1,175	1,526	50	2,054	....
Southern Ohio	2,010	....	....	....	....
Kanawha (W. Va.), Logan and Kenova-Thacker (W. Va.-E. Ky.)	854,811	127,639	1,486	57,419	1,953
New River-Winding Gulf and Pocahontas-Tug River (W. Va.)	5,908,215	392,942	194,074	532,527	149
Northeast Kentucky and McRoberts	696,218	225,820	1,894	62,523	91
Virginia	56,084	14,040	490	23,710	....
Harlan and Hazard (E. Ky.)	1,294,290	385,414	3,286	53,118	1,250
Ex-River Coal	243	51	....	....	....
Northern Illinois	623,439	1,216,138	154	16,812	....
Central and Southern Illinois	4,922,351	5,219,466	10,872	409,127	45,241
Indiana	2,701,214	995,944	28,629	336,083	651
Western Kentucky	646,009	507,085	8,178	255,947	10,183
Total	17,757,618	9,093,110	249,802	1,754,181	60,111

[a] Data from Monthly Coal Distribution Report 32, U. S. Bureau of Mines, March, 1934.

INDIANA AND WESTERN KENTUCKY AND FROM THE APPALACHIANS (EXCLUSIVE OF NON-REVENUE FUEL) [a]

Iowa, other	St. Louis	Kansas City	St. Joseph	Missouri, other	Kansas, other	Nebraska, other	Minnesota	South Dakota	North Dakota
				1932					
1,379	102	...	...	...	...	...	...	...	...
2,435	1,062	1,317	411	2,125	1,317	1,175	3,503	1,029	...
3,054	52	...	...	...	...	155	651	361	...
948	...	...	...	...	...	...	35	...	...
166	...	...	...	...	...	...	...	...	...
252,846	41,137	89	...	4,804	89	861	27,980	4,841	...
87,114	73,317	...	...	637	...	81	223,095	32,900	...
206,139	203,585	...	...	108	...	697	46,400	6,115	...
5,213	52	...	...	...	...	...	9,068	461	...
473,569	12,366	...	48	4,044	...	2,584	55,853	13,003	...
...	...	...	...	...	...	...	...	...	...
178,236	209	...	...	192	...	32	119,518	892	75
1,295,142	2,883,363	12,739	21,707	928,259	21,504	136,741	326,604	105,697	482
303,999	70,638	101	...	9,106	...	7,127	124,287	2,772	148
621,262	426,477	...	...	287,788	240	19,662	146,432	58,895	3,392
3,431,502	3,712,900	14,246	22,166	1,237,063	23,891	169,115	1,083,426	226,966	4,097
				1933					
2,647	23	...	...	53	...	...	...	45	...
2,786	2,074	638	248	1,846	1,199	1,278	4,223	1,149	...
3,048	...	...	...	35	...	109	1,216	252	...
1,870	...	...	...	...	...	...	238	293	...
322	...	...	...	...	...	...	...	...	...
208,094	42,586	43	...	3,191	35	340	31,207	4,299	...
86,807	65,644	...	89	750	83	134	197,457	27,590	...
170,380	179,463	...	...	868	...	412	40,154	7,747	...
3,986	142	...	...	...	...	...	8,149	513	...
425,256	11,251	...	...	2,750	...	1,133	45,069	12,312	...
...	...	...	...	...	...	...	...	...	...
266,983	...	...	...	...	...	...	61,856	954	...
1,288,290	2,630,143	4,343	14,759	816,659	15,202	103,930	297,789	81,235	672
282,932	60,246	105	...	4,134	...	5,021	137,232	18,649	584
398,858	123,562	...	...	152,053	...	16,303	96,904	35,678	2,885
3,142,259	3,115,134	5,129	15,096	982,339	16,519	128,660	921,494	190,716	4,141

(Continued on next two pages)

TABLE 6 CONCLUDED.—ORIGIN AND DESTINATION OF REVENUE RAILROAD SHIPMENTS FROM NON-REVENUE

From	Chicago	Illinois, other	Milwaukee	Wisconsin, other	Council Bluffs
1934					
Western Pennsylvania	19,858	1,530	340	496	....
Altoona, Somerset-Meyersdale and Cumberland-Piedmont	31,455	4,674	413	2,586	772
Fairmont (W. Va.)	10,864	7,555	92	1,323	....
Northern and Eastern Ohio	2,120	....	....	944	....
Southern Ohio	3,201	280	....	493	....
Kanawha, (W. Va.) Logan, and Kenova-Thacker (W. Va.-E. Ky.)	865,362	105,197	1,421	42,798	1,274
New River-Winding Gulf and Pocahontas-Tug River	5,987,987	417,313	122.516	534,235	77
Northeast Kentucky and McRoberts.	812,537	236,818	601	43,192	....
Virginia	86,865	14,051	....	25,941	....
Harlan and Hazard (E. Ky.)	1,136,387	279,383	1,513	46,481	618
Ex-River Coal	....	248	....	....	....
Northern Illinois	660,261	1,720,818	162	53,130	44
Central and Southern Illinois	5,013,206	5,697,164	16,293	665.931	42,455
Indiana	2,778,257	1,005,808	46,403	471,015	1,466
Western Kentucky	560,775	334,767	1,442	301,323	7,707
Total	17,969,135	9,825,606	191,196	2,189,888	54,413

[a] Data from U. S. Bureau of Mines, Monthly Coal Distribution Reports.

Illinois, Indiana and Western Kentucky and From the Appalachians (Exclusive of Railroad Fuel) [a]

Iowa, other	St. Louis	Kansas City	St. Joseph	Missouri, other	Kansas, other	Nebraska, other	Minnesota	South Dakota	North Dakota
				1934					
521	....	17	....	....	....	....	172	38	......
3,011	3,331	859	417	2,008	1,261	1,508	4,509	1,454	......
2,313	....	....	....	....	....	....	475	167	......
4,453	....	....	....	....	....	....	239	73	......
487	....	....	....	....	....	....	100	....	......
179,372	42,399	....	....	2,819	....	438	25,194	2,979	......
86,465	59,558	....	....	681	218	393	139,063	17,995	......
158,901	177,011	50	....	1,737	....	716	28,162	4,379	......
4,142	183	....	....	....	....	....	8,630	363	......
375,048	6,258	....	....	1,820	....	1,302	38,661	8,890	......
....	....	....	....	....	....	....	....	....	......
311,550	96	....	....	....	....	....	50,118	1,827	......
1,350,047	2,939,703	3,813	21,193	790,262	13,833	114,712	374,372	100,772	1,234
361,770	44,528	97	....	1,310	....	4,906	149,836	24,064	491
268,983	96,051	189	....	113,548	....	15,138	72,039	26,947	3,524
3,107,063	3,369,118	5,025	21,610	914,185	15,312	139,113	891,570	189,948	5,249

Table 7.—Summary of Revenue Railroad Shipments From Illinois, Indiana, and Western Kentucky and West Bound From the Appalachian Fields[a] *(Exclusive of Non-revenue Railroad Shipments)*

Market District	Total Shipments			Illinois Shipments			Percent from Illinois		
	1932	1933	1934	1932	1933	1934	1932	1933	1934
Chicago	16,554,379	17,757,618	17,969,135	4,466,098	5,545,390	5,673,467	27.0	31.4	32.1
Illinois, other ([b])	10,156,448	9,093,110	9,825,572	6,699,697	6,430,604	7,417,982	61.0	71.3	75.5
Milwaukee, Wis	207,688	249,802	191,196	11,297	11,026	16,455	5.4	4.4	5.6
Wisconsin, other	1,653,632	1,754,181	2,189,888	336,127	425,939	719,061	20.3	24.7	33.0
Council Bluffs, Iowa ([c])	122,305	60,111	54,413	94,565	45,241	42,499	77.2	76.0	78.0
Iowa, other	3,431,502	3,142,259	3,107,063	1,743,378	1,555,073	1,661,597	42.9	50.2	53.5
St. Louis, Mo. ([d])	3,712,900	3,115,134	3,369,118	2,883,572	2,598,993	2,939,799	77.5	84.9	87.2
Kansas City, Mo. ([e])	14,246	5,129	5,025	12,739	4,343	3,813	89.4	84.5	75.7
St. Joseph, Mo. ([f])	22,166	15,096	21,610	21,707	14,759	21,193	97.8	92.6	97.9
Missouri, other	1,237,063	982,339	914,185	928,451	814,159	790,262	75.0	83.9	86.4
Kansas, other	23,891	16,519	15,312	21,504	15,202	13,833	89.8	92.0	90.1
Nebraska, other	169,115	128,660	139,113	136,773	103,930	114,712	80.6	81.2	82.4
Minnesota	1,083,426	921,484	891,570	446,122	359,645	424,490	41.1	39.4	47.5
South Dakota	226,996	190,716	189,948	106,589	82,189	102,599	46.8	43.6	53.9
North Dakota	4,097	4,141	5,249	557	672	1,234	13.6	16.8	23.3
Total	38,619,824	37,114,880	38,888,397	17,639,176	18,007,165	19,942,996	45.5	48.4	51.3

[a] Data from U. S. Bureau of Mines, Monthly Coal Distribution Reports.

[b] Includes Davenport, Iowa, for shipments from Ohio and the Crescent; and includes Davenport, Bettendorf, and Iowa, for shipments from the Interior field; excludes East St. Louis.

[c] Includes Omaha, and South Omaha, Nebraska.

[d] Includes East St. Louis, Illinois.

[e] Includes Kansas City, Kansas.

[f] Includes Atchison and Leavenworth, Kansas.

TABLE 8.—BITUMINOUS COAL SHIPMENTS TO LAKE SUPERIOR AND LAKE MICHIGAN PORTS, 1929-1934[a]

(In thousands of tons)

Year	Superior	Michigan	Total
1934	8,569	10,912	17,481
1933	6,909	10,267	17,176
1932	6,221	7,066	13,287
1931	8,502	9,216	17,718
1930	([b])	12,056	......
1929	([b])	12,533	......

[a] U. S. Bureau of Mines, Monthly Coal Distribution Reports.
[b] Not available.

TABLE 9.—RECEIPTS OF BITUMINOUS COAL AT UPPER LAKE DOCKS, 1931-1934[a]

(In thousands of tons)

Year	Superior	Michigan	Total
1934	8,023	4,534	12,557
1933	6,502	4,565	11,067
1932	5,949	3,663	9,612
1931	7,673	4,454	12,127

[a] All commercial American docks on Lake Superior and west bank of Lake Michigan as far south as Racine and Kenosha; not including Waukegan and Chicago. U. S. Bureau of Mines, Monthly Coal Distribution Reports.

TABLE 10.—LAKE CARGO BITUMINOUS COAL SHIPMENTS TO THE CHICAGO DISTRICT, 1920-1933[a]

(In thousands of tons)

Year	Port of Chicago	Chicago Harbor	Chicago River	Calumet Harbor and River	Indiana Harbor
1920	687	6	..	681	...
1921	376	..	..	376	725
1922	596	..	..	596	790
1923	1,251	35	..	1,217	1,263
1924	723	69	..	854	1,123
1925	1,472	62	..	1,410	1,280
1926	1,968	15	103	1,850	1,000
1927	1,686	4	24	1,658	1,503
1928	2,785	55	..	2,730	1,644
1929	2,654	67	54	2,533	1,670
1930	2,238	52	37	2,149	1,474
1931	1,584	71	12	1,500	868
1932	1,204	81	17	1,106	515
1933	1,512	64	100	1,348	688

[a] Data from Annual Reports of U. S. Corps of Engineers, War Department.

TABLE 11.—LAKE CARGO ANTHRACITE SHIPMENTS TO THE CHICAGO DISTRICT, 1920-1933 [a]
(In thousands of tons)

Year	Port of Chicago	Chicago Harbor	Chicago River	Calumet Harbor and River
1920	737	508	...	229
1921	556	379	...	187
1922	194	170	...	24
1923	583	378	...	205
1924	505	389	...	116
1925	217	160	...	57
1926	244	...	232	12
1927	88	...	83	6
1928	107	24	76	6
1929	37	...	37	...
1930	56	6	50	...
1931	32	...	32	...
1932	9	...	9	...
1933	12	...	12	...

[a] Data from Annual Reports of U. S. Corps of Engineers, War Department.

TABLE 12.—LAKE CARGO COAL SHIPMENTS TO MILWAUKEE, 1920-1933 [a]
(In thousands of tons)

Year	Bituminous	Anthracite	Coke
1929	3,950	487	...
1930	3,665	445	27
1931	3,070	308	16
1932	2,656	148	44
1933	3,476	161	73

[a] Data from Annual Reports of U. S. Corps of Engineers, War Department.

TABLE 13.—LAKE CARGO COAL SHIPMENTS TO DULUTH-SUPERIOR, 1921-1933 [a]
(In thousands of tons)

Year	Bituminous coal	Anthracite
1921	8,320	1,845
1922	5,139	566
1923	11,268	1,420
1924	7,731	1,290
1925	8,883	790
1926	9,169	1,273
1927	11,452	981
1928	9,688	652
1929	10,330	401
1930	9,342	461
1931	7,357	300
1932	5,651	65
1933	6,179	135

[a] Data from Annual Reports of U. S. Corps of Engineers, War Department.

Coal production in other states within the Illinois market area.—In addition to shipments of coal from the Appalachian, Indiana, and western Kentucky fields by rail and rail-lake hauls, the Illinois coal industry shares the market with local production in states west of Mississippi River. Production in these states, 1930-1934, is as follows:

TABLE 14.—COAL PRODUCTION IN IOWA, KANSAS, MISSOURI, AND THE DAKOTAS
(In thousands of tons)

Producing State	1930	1931	1932	1933	1934
Iowa	3,893	3,388	3,862	3,195	3,345
Kansas	2,430	1,987	1,953	2,218	.....
Missouri	3,853	3,621	4,070	3,432	5,800
North Dakota	1,700	1,519	1,740	1,782	1,770
South Dakota	13	27	49	59	60
Total	11,889	10,542	11,674	10,686	10,975

TABLE 15.—STRIP-MINED COAL IN ILLINOIS, 1929-1934

Year	Output, tons	Percent of total output
1929	5,374,813	8.8
1930	6,116,415	11.3
1931	6,262,501	14.6
1932	6,423,935	20.4
1933	5,423,796	15.4
1934	5,777,202	14.1

Fuel briquets.—Distribution of fuel briquets in 1934 increased over the previous year in the Illinois coal market area and is again nearly equal to sales in 1931.

TABLE 16.—BRIQUETS CONSUMED FOR DOMESTIC FUEL IN THE ILLINOIS COAL MARKET AREA, 1931-1934[a]
(In net tons)

State	1931	1932	1933	1934
Illinois	7,918	5,474	6,218	12,606
Wisconsin	77,907	65,872	89,131	104,885
Minnesota	200,583	137,292	133,102	168,067
Iowa	23,843	18,310	19,269	22,713
Missouri	4,271	3,005	4,360	5,904
North Dakota	52,288	43,915	46,746	50,525
South Dakota	39,490	29,999	28,704	34,401
Nebraska	16,975	8,245	8,992	16,171
Kansas	10,033	6,262	4,243	5,278
Total	433,308	318,374	340,765	420,550
Total for the United States	688,258	485,288	529,162	703,592

There are nine briquetting plants in operation in the Illinois coal market area with the following locations, dates on which these plants were put in operation, and the raw materials used.

TABLE 17.—BRIQUETTING PLANTS IN THE ILLINOIS COAL MARKET AREA

State	Location	Date plant was put in operation	Raw materials used
Minnesota	Duluth	1933	Anthracite & bituminous slack
Missouri	Kansas City	1909	Semi-anthracite
Nebraska	Omaha	1933	Anthracite & bituminous slack
North Dakota	Lehigh	1929	Lignite char
Wisconsin	Superior	1912	Bituminous slack
Wisconsin	Ashland	1931	Bituminous slack
Wisconsin	Superior	1909	Anthracite & bituminous slack
Wisconsin	Milwaukee	1928	Bituminous slack
Wisconsin	Sheboygan	1933	Bituminous slack

[a] U. S. Bureau of Mines, Weekly Coal Report No. 926, April 13, 1935.

The Illinois coal market area uses about 60 per cent of the briquets made in the United States. This is mainly the result of an attempt to use the slack coal produced in the handling of coal over the lake docks or, in the case of North Dakota, to utilize lignite. As a consequence the heaviest sales of briquets are near the sources of supply—Minnesota, Wisconsin, and North Dakota. In Illinois and Missouri where no plants are as yet located, the sale of briquets is extremely low. Development of a market for briquets will be somewhat more difficult in these states in view of the fact that bituminous coal for domestic purposes is sold at a lower price than in the states tributary to the lake docks territory. Prices of fuel briquets in the Central States is shown in Table 18 below.

TABLE 18.—AVERAGE VALUE PER NET TON *(f. o. b plant)* OF BRIQUETS PRODUCED IN THE CENTRAL STATES, 1923-1934

Year	Value	Year	Value	Year	Value
1923	$9.35	1927	$8.30	1931	$8.11
1924	9.00	1928	8.38	1932	7.60
1925	8.72	1929	8.13	1933	6.71
1926	8.86	1930	8.13	1934	6.54

Trend in natural gas consumption.—Importation of natural gas into the Illinois coal market area continued its upward trend in 1934 over previous years although the rate of growth is declining. Detailed data on natural gas distribution and consumption is not yet available. Natural gas consumption was extended into Minnesota in 1934 but beyond that no other significant extensions were made.

TABLE 19.—NATURAL GAS IMPORTED INTO THE ILLINOIS COAL MARKET AREA[a]
(In millions of cubic feet)

From	1928	1929	1930	1931	1932	1933	1934
To Illinois							
Kansas				26	719	974	2,019
Louisiana		156	6,712	7,553	8,330	10,704	10,971
Missouri				175	223	178	164
Texas				4,166	18,348	19,766	29,952
Kentucky					49	67	111
Indiana					6	24	3
Total		156	6,712	11,920	27,675	31,713	43,220
To Missouri							
Kansas	9,406	14,635	20,284	3,033	3,771	3,731	4,716
Louisiana		133	5,464	5,406	7,673	8,279	9,274
Oklahoma				5,447	3,607	2,516	2,880
Texas				9,217	9,822	12,638	12,597
Total	9,406	14,768	25,748	23,103	24,873	27,164	29,467
To Iowa							
Kansas			8	1,795	4,641	6,526	5,617
Texas				1,727	2,892	4,882	11,019
Total			8	3,522	7,523	11,408	16,636
To Nebraska							
Kansas			1,098	2,802	5,340	6,215	6,323
Oklahoma				31	39	89	181
Texas				1,837	2,677	3,235	5,473
Wyoming				147	605	754	812
Total			1,098	5,817	8,661	10,293	12,789
Grand total	9,406	14,924	33,666	43,362	68,732	80,578	102,112

[a] Annual Mineral Resources of the United States, U. S. Bureau of Mines.

TABLE 20.—CONSUMPTION OF NATURAL GAS IN THE ILLINOIS COAL MARKET AREA, 1929-1932
(In millions of cubic feet)

	Illinois	Iowa	Missouri	South Dakota	Nebraska
1929					
Domestic	94	....	7,224	8,700	....
Field	2,895	....	12	....	....
Petroleum refineries	....	....	....	....	....
Electric utility plants	....	....	456	....	....
Industrial	150	....	7,386	847	....
Total	3,139	....	15,078	1,717	....
1930					
Domestic and commercial	115	....	9,158	1,172	180
Field	2,806	....	3	....	....
Petroleum refineries	149	....	2,422	....	....
Electric utility plants	....	....	966	....	263
Industrial	6,532	....	13,573	1,733	655
Total	9,602	....	26,122	2,905	1,098
1931					
Domestic and commercial	3,631	471	9,734	1,142	1,163
Field	2,038	....	7	....	....
Petroleum refineries	11	....	1,106	....	....
Electric utility plants	....	358	1,106	....	1,084
Industrial	8,370	2,693	12,308	1,661	2,570
Total	14,050	3,522	24,261	2,803	4,817
1932					
Domestic and commercial	16,113	1,328	11,684	1,350	2,605
Field	1,722	....	3	....	....
Petroleum refineries	136	....	18	....	....
Electric utility plants	....	1,314	1,867	62	1,726
Industrial	11,461	4,891	11,738	1,364	4,330
Total	29,432	7,533	25,310	2,776	8,661
1933					
Domestic and commercial	17,272	2,199	11,938	1,361	3,107
Field	1,573	....	18	....	....
Petroleum refineries	179	....	....	....	....
Electric utility plants	....	2,259	2,218	128	1,701
Industrial	14,353	6,950	13,405	1,775	5,485
Total	33,377	11,408	27,579	3,264	10,293
1934					
Domestic and commercial	19,628	3,501	12,109	1,505	3,459
Field	1,435	....	12	....	....
Petroleum refineries	646	....	3	....	....
Electric utility plants	358	3,249	2,668	473	2,262
Industrial	23,017	9,886	15,000	1,923	7,068
Total	45,084	16,636	29,792	3,901	12,789

PETROLEUM

Production and price.—The production of crude petroleum in Illinois in 1933 and 1934, by months, is given in Table 21.

Table 21.—Petroleum Production in Illinois, 1933-1934

Month	1933	1934	Month	1933	1934
January	297,000	393,000	July	404,000	394,000
February	263,000	337,000	August	411,000	402,000
March	314,000	394,000	September	412,000	378,000
April	284,000	373,000	October	406,000	352,000
May	313,000	411,000	November	388,000	305,000
June	357,000	392,000	December	378,000	321,000
First 6 months	1,828,000	2,300,000	Year	4,227,000	4,452,000

The average price of Illinois petroleum in 1934 was $1.13 as compared with $0.87 in 1933 and $1.03 in 1932.

The quotas of allowable production for Illinois during 1934, as authorized by the Federal Oil Administrator, were as follows:

	Bbls. per day
January to March, inclusive	12,000
April, May	12,500
June, July	12,600
August	12,500
September to November, inclusive	12,000
December	11,700

In addition to the restrictions imposed by the Federal Oil Administrator, a restriction of 25 per cent below the Federal allowable was imposed on October 11th and continued until December 15th, when curtailment was reduced to 18 per cent. On December 18th, it was further reduced to 15 per cent.

Statistical summary.—In Table 22 are given the data on petroleum refining and consumption as far as the information is available.

Table 22.—Statistical Summary of the Industry

	1933	1934
Production	4,227,000	4,452,000
Daily Average	11,581	12,197
Receipts from other States	29,466,000	[a]
Runs to stills	33,386,000	[a]
Delivery to other States	341,000	[a]
Exports	653,000	[a]
Production of gasoline	17,623,000	
Consumption of gasoline	23,119,000	
Refinery capacity (daily)	128,050	

[a] Not available.

The petroleum industry in 1934.—The outstanding feature of the petroleum industry in 1934 has been a growing conviction that easily obtainable production from flush pools is not unlimited and inexhaustible and that a careful inventory of reserves from all sources and their most effective and complete recovery is essential if adequate annual flow of oil is to be maintained.

The discovery of new pools in each of the oil production states shows a gradual approach to a maximum followed by a decline and ultimate cessation. In Ohio, for example, the first pool was discovered in 1859. Progress was slow until 1895 when 8 pools were discovered, and until 1905, with two exceptions, several pools were discovered each year. Since 1905 only three pools have been discovered in Ohio, the last one in 1924. In Pennsylvania, the record of discovery is larger than Ohio and covers a longer period but no discoveries have been made since 1926. In Indiana the latest discovery occurred in 1928 and in West Virginia in 1930. New discoveries are always possible but the rate of discovery is diminishing.

With respect to new and proved reserves added each year to the nation's visible supply of oil, the situation is also critical in spite of the current abundant supply.

Important oil field discoveries have been relatively scarce during the past four years and new reserves are slower in yielding to the industry's test wells. Meanwhile, the existing flush fields have been gradually but appreciably dissipating their productive ability. In this connection it may be of interest to examine a table on the production and discovery experience of the American oil-producing industry by periods, as shown in Table 23.

TABLE 23.—ANALYSIS OF PRODUCTION AND DISCOVERY EXPERIENCE OF THE AMERICAN OIL-PRODUCING INDUSTRY BY PERIODS [a]

(1)	(2)	(3)	(4)	(5)	(6)
1859–1900........	25	80	0.3	0.3	0.003
1901–1905........	105	340	0.3	0.3	0.01
1906–1910........	175	275	0.4	0.6	0.01
1911–1915........	250	500	0.4	0.5	0.02
1916–1920........	370	585	0.5	0.6	0.02
1921–1925........	650	820	0.6	0.8	0.03
1926–1930........	895	1,990	0.5	0.4	0.07
1931–1934........	870	580	0.6	1.5	0.02

Column No. 1—periods analyzed.
2—average annual production in millions of barrels.
3—average annual discoveries in millions of barrels.
4—ratio of accumulated production to accumulated discoveries.
5—ratio of average annual production to average annual discoveries.
6—ratio of average annual discoveries to total discoveries for all periods.

[a] Prepared by Wallace E. Pratt, Vice-President of the Humble Oil and Refining Company, Oil and Gas Journal, May 2, 1935.

Of particular significance are the data presented in columns (4) and (5) of this table. Consumption has been gradually gaining upon new discoveries until it has risen from 0.3 of total discoveries to 0.6. As shown in column (4) and in the period 1931-1934, current production has exceeded current discoveries by 50 per cent. Only through the discovery of several large pools in the previous five-year period has it been possible to provide an ample supply of motor fuel to the consuming public since 1931. In the meantime, the rate of drilling during the depression years has fallen off less than the rate of new discoveries and in 1934 and 1935 again showed a substantial increase.

The proved oil reserves now in sight, according to a report to a subcommittee of the Committee on Interstate and Foreign Commerce of the House of Representatives, are placed at 13,360,000,000 barrels, as is shown in Table 24 taken from this report.

TABLE 24.—ESTIMATED OIL RESERVES OF THE UNITED STATES [a]

State	Total production of oil to Dec. 31, 1933. Barrels	Total estimated oil reserves as of Dec. 31, 1933. Barrels
Arkansas	396,801,000	29,500,000
California	4,036,663,000	5,422,500,000
Colorado	29,500,000	8,500,000
Illinois	412,263,000	34,000,000
Indiana	120,145,000	5,000,000
Kansas	703,624,000	194,000,000
Kentucky	129,296,000	30,000,000
Louisiana	512,937,000	136,000,000
Michigan	28,211,000	17,000,000
Montana	45,979,000	57,000,000
New Mexico	58,810,000	92,500,000
New York	85,454,000	45,000,000
Ohio	563,041,000	34,000,000
Oklahoma	3,514,263,000	844,500,000
Pennsylvania	878,360,000	252,500,000
Texas	3,415,309,000	5,884,000,000
West Virginia	384,373,000	27,500,000
Wyoming	374,732,000	245,000,000
Others	618,000	1,500,000
Total	15,690,379,000	13,360,000,000

[a] Hearings before a subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73rd Cong., H. Res. 441, Part 2, p. 1081.

The estimate of reserves given above is based upon existing methods of production. The recoverable oil represents a part, estimated at from 25 to 35 per cent of the oil in the reservoir. It does not consider the reserve that can be recovered by improved methods of production or the oil obtainable under a higher price level for crude. This estimated reserve of oil, if withdrawn at the rate of 900,000,000 barrels annually, would last about 15 years provided no new fields were found in that time or methods of augmenting the supply from existing pools are devised. Practically, it will be impossible to produce the full amount of the estimated reserves in even 25 years. As a field approaches the end of its productivity the rate at which oil can be taken out gradually declines. The effect of this has been, in the absence of major pool discoveries since 1930, to increase the relative importance of stripper well areas as ultimate sources of supply.

The existing curtailment of production has been necessary primarily because of the danger of unmanageable surplusses from East Texas and other prolific pools. But the present potential output in excess of current demand conceals a situation of impending shortage unless steps are taken to increase the rate of discovery or increase recovery from existing fields.

The position of the stripper well.—In view of the need of searching now for the means of supplying the oil needed in 1940, it is obviously unwise to seek new and untried sources such as alcohol, oil shale, or motor fuel from coal, and at the same time impose hampering restrictions upon existing sources of potential motor fuel supply. The importance of the stripper well cannot be judged entirely from its annual contribution to crude oil production, though that may appear to be small. For example, the petroleum output of the states[1] with wells averaging less than 1.1 barrel per day was, in 1934, 37 million barrels. This, however, does not indicate the total production from stripper wells since there are large numbers of these wells in the large oil producing states whose average production per well per day is substantially above one barrel, and in the Gulf Coast of Louisiana, reaches 108 barrels per day. In these states the number of stripper wells is concealed in the high output of a few flush wells.

The second factor that must be considered in evaluating the importance of the stripper well is the duration of production from stripper wells as compared with the spectacular pools of high initial production and prolific flow for a limited period. Although the output per well per day in Illinois, at a maximum, was about 9.7 barrels per well per day and that only for a short period; nevertheless, the total yield of the southeastern Illinois field is exceeded only by four other fields in the United States.[2]

Finally, the decreasing rate at which flush pools are being discovered and brought into production is gradually bringing about a lower percentage of the annual supply from this type of pool and increasing the proportional supply from the smaller wells. With each succeeding week, as the production of new wells is reported, the absence of any major discoveries serves to increase the nation's dependence upon small producers.

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[1] Illinois, Pennsylvania, Ohio, Kentucky, West Virginia, New York, Indiana and Tennessee.

[2] (1) Sunset-Midway, California; (2) East Texas; (3) Seminole, Oklahoma; (4) Long Beach, California.

If, in the light of current conditions of demand and new discovery, the producers of petroleum are expected to make their utmost contribution to the future oil supply of the United States, a practical policy of conservation of these pools must be planned and carried out. If, in the interests of a continued oil supply, in which the oil industry is just as vitally interested as is the consumer, it becomes necessary, temporarily, to curtail production in order to reduce the current unmanageable surplusses and prevent new ones from appearing, it is not unreasonable to restrain the flow of new oil as long as the existing production faculties can meet current demand. Specifically, the control of oil in the East Texas field will do much to restore the demand-supply balance and will ultimately react to the benefit of the several owners and producers in this field.

With regard to wells in the stripper class, the soundest program of conservation and greater ultimate recovery is the removal of all restrictions. The hope of greater ultimate recovery in the stripper well districts, whether they be located in Illinois, Pennsylvania, Kansas or elsewhere, lies in increasing the flow by improved recovery methods. But there can be no incentive for investment in improved recovery methods unless two conditions are met: (1) investment in these methods must reduce the per barrel lifting costs, or conversely, must yield an additional quantity of oil which is greater in value than these added investment costs; (2) the benefits of increased recovery must not be nullified by artificially imposed restrictions. In addition to the normal handicaps of higher production costs, the stripper wells have just passed through a period of unusually severe price drops occasioned by the sudden appearance of several large fields and intensified by the general fall in price levels since 1929. That this situation cannot endure indefinitely is obvious. The continuance of the small well and the hope of increased recovery from the small well is contingent primarily upon the removal of all production restrictions upon the operators. The necessity of this is evident from a comparison of operating and total costs in certain selected fields.

TABLE 25.—COSTS OF OIL PRODUCTION, EXCLUSIVE OF INTEREST CHARGES, 1931-1933 [a]

State	Depletion	Depreciation	Amortization	Operating Costs	Overhead Costs	Total
Illinois	.06	.23	02	.70	.24	1.25
Texas	06	09	04	.14	.28	.61
Kansas	09	22	07	.24	.33	.95
Pennsylvania	25	34	22	58	.19	1.58
East Texas	032	063	050	.082	.267	.494
Oklahoma City	076	119	121	.123	.283	.722

[a] United States Department of the Interior, Petroleum Administrative Board, "Preliminary Report on a Survey of Crude Petroleum." Cost of Production for the Years 1931-1933 and Comparison with Years 1927-1930, p. 8.

The practical value of improved methods of recovery has been demonstrated in Pennsylvania where no new pools of significant size have been discovered since 1920. Experiments in Pennsylvania with flooding the oil sands as well as repressuring with gas and air began in 1921 but did not begin to show appreciable results until 1925, and as a result of the application of improved methods of recovering oil, the production rose from 7,438,000 barrels in 1920 to 14,666,000 in 1934.

The low production costs for a particular pool at a time of flush production are below the average cost of production over the entire life of the pool but these low costs affect for the time being the entire price structure.

Now if the country could be assured of the discovery and opening up of flush pools in rapid succession and properly timed, for an indefinite future, then this type of production could be looked upon as normal, the need for improved production practices, such as have been discussed here would disappear, and the stripper well would go permanently into the submarginal class. But the assumption of a continuing occurrence of flush pools cannot be justified. To frame an oil policy on this basis, which would mean the extinction of the stripper well, would result in periods of underproduction with high prices to the consumer, and a dislocation of the price structure in the oil industry which would be just as bad in one direction as ruinously low prices are in the other direction.

The alternative is to consider the small wells of the country as a back-log of assured production during the intervals between flush pool production. As such, an economic policy must be framed which will protect the life of these wells. As such, the basis of their continuance must not be measured by the price of distress oil from flush pools that is thrown upon the market utterly regardless of the existing conditions of demand, but must be measured on a basis of overall costs of production that are necessary to keep the country adequately supplied with oil from both big and small wells. This may look like a subsidy for the small wells, but it is doubtful in fact, if such is the case. For example, if, by the iron law of uncontrolled competition, the flush pools were allowed temporarily to govern the price, and the small wells suffered extinction, then with the first lull in flush production output, the prices would rise and also expenditures to revive production in abandoned fields or to find oil in hitherto unexplored fields. These total expenditures may quite likely exceed the expenditure of supporting the small wells through flush and lean periods.

CLAY PRODUCTS

The value of clay products in 1934 was $5,945,199.60, of which structural clay products represented $4,498,959.73 and pottery was valued at $1,446,239.27. Compared with previous years there was a slight increase in total value but a decline in the value of pottery products (Table 26).

Table 26.—Value of Clay Products, 1932 to 1934

	1932	1933	1934
Structural and refractory clay products	$2,504,610	$2,328,556	$4,498,960
Pottery	1,837,033	1,816,467	1,446,239
Total	$4,341,643	$4,145,033	$5,945,199

Production of clay products, by types, in 1934 is given in Table 27.

Table 27.—Production of Clay Products, by Classes, 1934

	Quantity	Value	Stocks on hand
Common brick (M)	64,073	$ 590,690.66	58,963
Face brick (M)	24,667	365,978.09	20,057
Hollow Building Tile (tons)	45,844	169,660.70	65,785
Drain Tile (tons)	17,597	128,962.56	16,689
Vitrified Brick or Block (M)	18,353	327,705.82	656,940
Refractory Clay Products	....	2,372,555.80	....
Other Clay Products	....	543,406.10	....
Pottery	....	1,446,239.87	....
Total		$5,945,199.60	

Table 28.—Production of Common Brick, by Principal Districts, in 1934

District	1934 Quantity thousands	1934 Value	Stocks on hand Dec. 31st (thousands)		
			1934	1933	1932
Chicago (Lake, Cook and Will counties)	35,649	$307,677.50	37,984	43,910	64,535
Northern Illinois (Bureau, Fulton, Knox, LaSalle, Livingston and Tazewell counties)	18,258	173,198.15	12,033	5,206	7,856
Central and Western Illinois (Henry, Macon, Menard and Sangamon counties)	2,935	29,736.17	4,572	([a])	2,778
East St. Louis district	4,948	53,635.84	2,635	1,827	2,799
Other	2,283	26,443.00	1,740	4,183	3,795
Total	64,073	$590,690.66	58,964	55,126	81,763

Production of common brick and stocks on hand in principal market districts of the State are shown in Table 28.

Stocks of structural clay products in the hands of producers continued to decline in 1934 as shown in Tables 29 to 31. In the three leading products—

Table 29.—Shipments of Common Brick in Illinois in 1932 to 1933 [a]

	Number of plants	Shipments		Thousands stocks on hand at end of month
		Thousands	Value	
1932				
January	39	4,307	$35,469	108,780
February	37	4,215	33,219	104,854
March	38	3,591	34,691	98,384
April	36	6,165	51,235	96,036
May	33	6,558	52,546	89,841
June	33	5,316	40,947	86,715
July	34	5,488	43,172	86,016
August	32	5,430	40,669	81,203
September	33	4,848	36,675	80,839
October	30	4,791	35,899	74,568
November	32	3,485	25,862	69,014
December	30	2,194	16,522	69,771
1933				
January	30	1,787	13,795	68,236
February	31	1,357	10,775	67,196
March	32	1,975	15,695	66,275
April	33	3,072	24,885	70,180
May	33	4,138	32,253	62,771
June	34	4,774	37,497	64,197
July	34	5,888	47,280	65,574
August	34	5,810	45,889	66,620
September	34	5,843	44,983	61,883
October	34	7,423	58,430	56,228
November	34	5,083	41,183	56,993
December	34	3,861	31,148	58,993
1934				
January	33	4,818	38,712	56,284
February	35	2,669	22,876	53,674
March	35	4,579	37,861	49,986
April	32	3,826	35,174	47,762
May	32	5,303	45,332	51,010
June	32	6,267	58,180	53,259
July	32	5,640	54,070	50,899
August	32	6,210	57,158	46,587
September	31	6,569	61,958	43,960
October	31	8,650	79,490	43,217
November	31	5,069	49,061	49,731
December	32	2,669	24,292	55,120

[a] Data from Monthly Report on "Structural Clay Products," U. S. Bureau of Census.

common brick, face brick, and hollow building tile—there were from ten to twelve months supply of stocks on hand on December 31st, based on the average monthly shipments for the current year.

TABLE 30.—SHIPMENTS OF FACE BRICK IN ILLINOIS IN 1932 TO 1934 [a]

	Number of plants	Shipments		Thousands stocks on hand at end of month
		Thousands	Value	
1932				
January	22	2,182	$30,945	51,867
February	20	2,212	32,227	47,851
March	22	2,443	35,186	53,654
April	19	3,918	62,071	48,801
May	18	3,479	53,447	42,702
June	18	3,615	53,168	41,502
July	19	2,978	41,695	42,726
August	18	3,124	43,604	39,657
September	18	3,182	42,222	41,039
October	15	2,950	40,502	36,827
November	17	1,622	20,297	36,863
December	18	734	9,034	46,668
1933				
January	18	932	11,718	46,811
February	18	605	7,778	45,700
March	19	1,212	16,581	46,166
April	19	1,576	20,937	45,245
May	19	2,117	28,901	43,777
June	20	2,826	34,898	41,866
July	20	2,913	39,382	32,972
August	21	3,152	42,175	31,844
September	21	2,367	31,148	31,607
October	20	2,167	30,633	29,735
November	20	1,690	23,184	29,148
December	20	1,268	17,833	26,863
1934				
January	20	1,071	14,620	25,387
February	19	810	11,751	24,891
March	19	1,350	19,663	23,612
April	17	1,529	23,331	26,730
May	17	2,608	42,920	27,057
June	17	2,791	46,751	26,675
July	17	2,958	51,044	25,322
August	17	2,931	52,033	24,768
September	17	2,768	47,793	23,229
October	17	2,983	50,865	23,421
November	17	1,931	33,154	23,103
December	17	927	15,617	23,281

[a] Data from Monthly Report on "Structural Clay Products," U. S. Bureau of Census.

TABLE 31.—SHIPMENTS OF HOLLOW BUILDING TILE IN ILLINOIS IN 1932 TO 1934 [a]

	Number of plants	Shipments		Thousands stocks on hand at end of month
		Thousands	Value	
1932				
January	19	3,484	$14,755	74,478
February	17	2,879	10,498	71,602
March	17	2,521	8,734	70,179
April	15	3,578	11,980	67,985
May	15	3,562	12,332	66,268
June	15	2,765	8,179	68,172
July	16	3,933	10,865	63,352
August	15	2,479	7,383	54,913
September	15	2,978	9,375	52,055
October	14	1,517	5,964	45,884
November	14	735	2,945	45,612
December	16	499	1,912	45,282
1933				
January	15	2,269	6,554	47,880
February	16	538	1,862	47,331
March	15	525	1,944	47,125
April	15	927	3,676	46,216
May	16	1,147	4,921	45,176
June	17	1,142	4,690	45,565
July	17	1,124	5,549	46,004
August	16	1,611	7,001	45,834
September	17	3,132	10,853	42,922
October	17	1,940	8,249	41,790
November	17	1,177	5,284	40,406
December	17	1,053	5,032	39,519
1934				
January	17	2,477	6,044	37,617
February	17	2,031	9,370	36,853
March	17	3,419	20,135	36,251
April	17	3,621	18,693	34,587
May	17	2,399	11,185	35,083
June	17	1,845	10,417	33,824
July	17	2,339	12,947	32,976
August	17	3,755	20,086	31,067
September	16	3,100	16,901	29,188
October	16	2,808	15,363	28,093
November	16	2,497	14,525	29,927
December	15	1,289	7,646	34,766

[a] Data from Monthly Report on "Structural Clay Products," U. S. Bureau of Census.

GLASS SAND

Economic possibilities of glass sand utilization in Illinois.—The unusually large supply of excellent glass sand in Illinois[1] raises the question of the economic possibilities of a more extensive manufacture of glass products in this state. At the present time Illinois exports substantial quantities of sand for glass making purposes while also importing glass products from distant sources. Although Illinois ranks first in glass sand output, it is fifth in value of manufacture of glass products. Glass manufacture began on the Atlantic Seaboard and moved westward with the movement of population, aided by the opportune discovery of natural gas fields in the Appalachian and Ohio Valley states. As long as glass making was done by hand, the abandonment of established factories in favor of new establishments near cheap fuel supplies and growing markets involved no great loss of capital investment and the migration of glass plants was rapid. With the introduction of expensive machinery, notably the Owens bottle making machine in 1895, with its high capital costs, glass establishments became more immobile, and there was a greater lag between the westward movement of markets and the migration of the glass industry. However, the location of industrial enterprises is constantly changing in favor of more economical relations between raw materials and markets, and the enlargement of glass making facilities in the midst of the large glass markets of the Upper Mississippi Valley will ultimately be brought about.

The logical step in evaluating the possibilities of an enlarged glass making industry in Illinois is to analyze the market conditions and point out the most favorable existing opportunities for the utilization of the available resources in the State.

Distribution of glass manufacture in the United States.—Seven states are important in the glass industry of the United States in the order named: Pennsylvania, West Virginia, Ohio, Indiana, Illinois, New York, and New Jersey. These states produce approximately 85 per cent of the value of glass goods. Other states with a significant industry are California, Missouri, Oklahoma, and Kansas. Table 32 gives the value of glass output, by percentages, in the seven leading states for specified years covering the period from 1909 to 1931. An examination of this table shows that the most significant increases have occurred in West Virginia and Illinois, both states with a surplus of glass sand, while those states which imported glass sand were practically stationary or showed declines in value of glass products.

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[1] Lamar, J. E., Geology and Economic Resources of the St. Peter Sandstone of Illinois: Illinois State Geol. Survey Bull. 53, 1927.

TABLE 32.—VALUE OF GLASS OUTPUT, IN PERCENTAGES, BY STATES FOR SPECIFIED YEARS

Year	Illinois	Indiana	New York	Ohio	Penna.	W. Va.	N. Jer.	Other
1931.....	9.0	13.0	5.4	17.9	23.2	15.0	5.4	13.1
1929.....	7.5	11.4	5.9	13.0	26.8	15.9	5.4	14.1
1927.....	7.6	12.5	5.7	12.0	27.8	15.6	5.5	14.1
1925.....	5.6	12.2	5.9	11.9	28.8	16.2	5.4	14.0
1923.....	5.4	13.2	5.0	11.1	32.0	16.2	5.0	12.1
1921.....	6.8	10.1	6.3	11.9	30.8	16.2	6.1	11.8
1919.....	6.9	13.5	5.0	13.5	30.9	16.3	5.2	8.7
1914.....	6.2	12.1	4.2	15.5	32,2	11.9	6.2	11.7
1909.....	5.5	12.5	4.4	15.6	35.6	8.4	7.6	9.9

The glass market.—The usefulness of glass in industry, in construction, and in household utensils is due to its properties of transparency, resistance to corrosion, and the ease with which it can be formed into sheets, tubes, rods, containers, decorative items, etc. Glass products fall into two general market groups, namely, those products which are manufactured directly for consumer use, and those glass products which enter into the construction of or form a part of a larger article of trade. The former group includes such items as tableware, fruit jars, lamp chimneys and globes, milk bottles, etc. The latter group is comprised of such items as building glass, beverage containers, lamp bulbs, chemical and pharmaceutical glassware. Market characteristics differ for each group and vary within the groups themselves. The market for that group of glass products which is sold directly to consumers will be governed by such items as distribution of population, variations in the purchasing power of population in different geographic areas, effect of style changes, and changes brought about by reason of fluctuations in purchasing power from one period to another. These same items also govern more or less the purchase of glass materials which are used by manufacturers in the fabrication of other consumer goods (for example, plate glass in an automobile) with this important difference: The immediate marketing point for glass products used in the further manufacture of goods is determined by the location of the fabricating plant or plants. Thus the market for approximately 50 per cent of the plate glass output is determined by the location of automobile factories, or another example, the market for lamp bulbs is determined by the location of electric lamp manufacturers. Again, the marketing point for certain types of glass goods is determined primarily by the location of factories using glass products in their operation, and in a secondary manner, by population distribution, as for example, bottles used in the beverage industry, where the industry itself is governed more of less by population distribution.

The market for certain types of glass products may, in some instances, be restricted to a very small number or even one producer when the product requires a high degree of skill or specialization or where one manufacturer is able to dominate the field to the exclusion of possible competitors. The complexities of market factors must be analyzed in an attempt to evaluate the feasibility of a new or enlarged glass manufacturing industry in a given locality.

Criteria for analyzing distribution of the glass market.—Since glass products are of many kinds and serve diverse uses in the home, in building construction, and in industry, an analysis of the distribution of glass products must take into account such elements as the distribution of population, rate of growth of population, movements of population to or from urban areas, building activities by regions or cities, location of industrial users of glass, changing demands for different types of glass products, etc.

Population.—Population of the United States, as of April 1, 1930, was 122,775,046 or an increase of 16.1 per cent during the preceding decade (1920—105,710,620). In the states which principally comprise the Illinois industrial market area the rate of increase during this same decade was 10.2 per cent, distributed among the individual states as follows:

TABLE 33.—POPULATION IN STATES COMPRISING THE ILLIOIS INDUSTRIAL MARKET AREA, 1920 AND 1930

State	1930	1920	Per cent Increase
Illinois	7,630,654	7,145,374	17.7
Wisconsin	2,939,006	2,632,067	11.7
Minnesota	2,563,953	2,387,125	7.4
Iowa	2,470,939	2,404,021	2.8
Missouri	3,629,367	3,404,055	6.6
North Dakota	680,845	646,872	5.3
South Dakota	692,849	636,547	8.8
Nebraska	1,377,963	1,296,372	6.3
Kansas	1,880,999	1,769,257	6.3
Total	23,866,575	21,661,596	10.2
Average	7,103,595	6,753,069	5.2

Table 33 presents an interesting comparison of population increases in agricultural vs. industrial states. If the dominantly agricultural states (Iowa, North Dakota, South Dakota, Nebraska, and Kansas) are segregated and the poulation increase calculated, it is found to be 5.2 per cent, which is less than one-third the increase for the State of Illinois. A further refinement of the data which would exclude the industrial population of such cities as Omaha, Sioux Falls, Kansas City, Wichita, and the population of oil and coal producing fields in these states would no doubt reduce the percentage of rural increase still further and merely emphasize a condition of agricultural maturity in this belt. This disparity in rates of population increase with the clearly indicated lack of demand for additional agricultural workers emphasizes the need of directing the energies of our population into different channels of productive activity.

Market trends.—The purpose of this inquiry is to ascertain as far as possible the trend of the glass market, the geographical distribution of glass consumption, and the relation of productive facilities to this distribution of consumption. In general the glass market is governed primarily by population distribution, qualified somewhat by variations in purchasing power in different localities, and also, by the demand of glass products used by manufacturing industries rather than ultimate consumers.

The market for glass products showed a consistent upward growth until 1923 after which the trend of output fluctuated more or less with the variation in industrial activity. The trend of production by quantities and values from 1904 to 1933 is shown in Tables 34 and 35. The recession in practically all items of manufacture in 1931 naturally was to be expected in the light of recent industrial conditions. A revival of plate and sheet glass, however, should occur with renewed building activity and automobile manufacture. The market for glass containers such as milk bottles, beverage containers, fruit jars, and for such industrial glass goods as electric lamp bulbs, will probably show less significant increases. The outlook for new products out of glass is problematical at present although articles such as glass bricks and new types of tableware are being offered. The most important immediate outlet is probably in the sheet and plate glass markets.

The importance of the Mississippi Valley as a market for glass products is indicated by a market survey of common window glass made by the U. S. Tariff Commission in 1929. The relative importance of this area compared with the entire country is shown in Table 36.

TABLE 34.—VALUE OF GLASS PRODUCTS BY SPECIFIED YEARS, 1899-1931[a]
(In thousands of dollars)

Product	1899	1904	1909	1914	1919	1921	1923	1925	1927	1929	1931
Polished plate glass		$ 7,978	$12,205	$14,733	$33,348	$37,261	$66,103	$57,207	$44,258	$50,192	$26,111
Window glass	$10,879	11,611	11,743	17,495	41,101	24,026	42,623	37,525	26,814	25,962	10,397
Obscured glass	732	972	1,359	2,417	4,300	2,547	5,114	6,916	5,092	5,256	2,364
Wire glass—rough				1,057	2,271	2,108	3,882	3,546	2,746	4,278	1,250
—polished				534	635	1,208	1,652	2,264	1,631	1,714	550
Pressed and Blown glass (total)	17,076	21,956	27,398	30,279	70,748	55,718	77,279	72,086	76,657	85,549	56,291
Tableware and ovenware								12,230	13,141	17,264	13,404
Pressed tumblers and goblets								8,679	7,774	14,780	2,844
Blown tumblers, etc								7,100	8,702		7,844
Lenses—motor vehicle								2,743	1,579	2,033	884
other										933	478
Lamps								427	458	571	542
Lamp chimneys								2,658	2,281	1,951	1,100
Lantern globes								867	636	671	382
Shades, globes, except electric light								10,315	8,154	9,977	6,591
Tubing								3,935	4,023	4,750	3,140
Bulbs for electric lights								23,132	29,909	32,619	19,082
Glass containers (total)	21,677	33,631	36,018	51,959	94,670	85,743	107,231	100,301	114,380	121,655	103,732
Milk bottles								10,588	11,480	11,696	9,725
Narrow neck blown bottles									11,665	10,209	8,843
Wide-mouth blown bottles									19,963	22,946	17,456
Pressed ware									2,447	2,593	1,862
Fruit jars (home pack)								6,641	11,358	8,525	15,103
Beverage containers—pressure ware									15,995	16,690	12,848
—nonpressure ware									1,724	1,776	2,563
Medicinal, toilet, etc									34,759	41,486	29,223
General purpose containers								83,072	4,989	5,734	6,109
Other glass products	6,176	3,459	3,372	4,611	14,811	1,694	1,885	6,133	4,752	5,110	6,347
Total value	56,540	79,607	92,095	123,085	261,884	210,305	304,769	285,978	276,330	299,716	207,042

[a] Data from U. S. Bureau of the Census.

Table 35.—Quantities of Glass Products by Specified Years, 1899-1931 [a]
(In thousands)

Product	1899	1904	1909	1914	1919	1921	1923	1925	1927	1929	1931
Polished plate glass (sq. ft.)	21,172	34,805	60,151	75,770	72,849	(b)	124,780	165,380	157,546	148,743	88,017
Window glass (sq. ft.)	217,064	242,615	346,081	400,998	368,912	260,065	510,214	567,151	481,021	402,559	268,272
Obscured glass, cathedral, sky-light, opalescent (sq. ft.)	52,526	21,871	22,815	43,040	33,822	20,901	46,376	53,951	41,545	34,294	17,649
Wire glass—rough (sq. ft.)				13,981	14,462	13,949	28,802	28,743	25,795	38,924	14,216
—polished				1,708	1,229	2,211	2,805	4,165	3,320	3,893	1,448
Pressed tumblers and goblets (doz.)		7,346	11,687	18,030	25,182			29,678	27,281		8,939
Lenses, motor vehicle, (doz.)					726					2,321	1,398
Lamp chimneys (doz.)	6,901	7,039	6,653	6,989	6,615			3,439	2,987	3,019	1,597
Lantern globes	1,045	1,765	953	1,364	1,986			1,080	869	942	404
Tubing, pounds					18,147			16,860	21,519	23,067	17,292
Glass containers											
Milk bottles, gross								2,086	2,180	2,610	2,054
Narrow-neck blown bottles, packers ware, gross									3,301	2,956	2,784
Wide-neck blown bottles, packers ware, gross									6,299	6,489	6,269
Pressed ware (packers ware), gross									763	761	822
Fruit jars (home pack) gross								1,288	1,515	1,153	2,082
Beverage containers, pressure ware, gross									3,739	4,130	3,403
Beverage containers, non-pressure ware, gross									413	437	584
Medicinal and toilet preparation containers pressed and blown (gross)									12,097	15,792	12,062
General purpose containers, gross									4,223	1,358	1,048

[a] Data from U. S. Bureau of the Census.
[b] No data.

Table 36.—Common Window Glass: Distribution of the Domestic Product From the Plants Covered by the Commission's Investigation to the Leading Markets in the United States, 1929

Market	Shipments of domestic companies	
	Thousand pounds	Per cent of total
Atlantic and Gulf coasts:		
New York City and vicinity	61,519	
New York City 37,584		
Clifton, N. J. 15,061		
Jersey City 4,965		
Newark, N. J. 3,909		
Philadelphia	15,199	
Boston	9,356	
Baltimore	5,829	
New Orleans	2,424	
Houston	2,192	
Beaumont	181	
Other	41,136	
Total	137,836	32.5
Pacific Coast:		
San Francisco	8,072	
Los Angeles	6,260	
Seattle	2,371	
Other	4,502	
Total	21,205	5.0
Interior:		
Chicago	35,560	
Detroit	25,701	
St. Louis	14,199	
Pittsburgh	9,329	
Minneapolis and St. Paul	8,642	
Cleveland	8,397	
Other	163,237	
Total	265,065	62.5
Total to all markets	424,106	100.0

This represents about 75 per cent of the total value of glass products and may be considered as fairly indicative of the market distribution of glass products.

In comparison with the large market outlet in the cities of the Upper Mississippi Valley, the eastern states still lead in the manufacture of glass products.

For example, in 1933, the percentage of output, by value, of the leading states was as follows:

	Per cent
Pennsylvania	26.8
West Virginia	15.9
Ohio	13.0
Indiana	11.4
Illinois	7.5
New York	5.9
New Jersey	5.4
Others	14.1
	100.0

The number of factories by types of products in each of the important states is shown in Table 37.

TABLE 37.—NUMBER OF GLASS FACTORIES, BY TYPES IN LEADING GLASS MANUFACTURING STATES [a]

State	Pressed and blown glassware	Bottles and hollow ware	Window glass factories	Polished plate glass factories	Wire, opalescent, fancy figure, rough and ribbed glass tile factories
Pennsylvania	26	19	3	7	6
West Virginia	34	5	6	1	6
Ohio	16	4	4	3	1
Indiana	7	9	1	2	4
Illinois	2	1	..	1	..
New York	9	6	..	..	1
New Jersey	6	6	..	..	..
Missouri	..	1	..	1	1
Kansas	..	..	1	..	..
Oklahoma	3	7	3	1	1
Total	103	58	18	16	20

[a] Data from Glass Factory Directory, National Glass Budget, Pittsburgh, Pa.

The preponderance of glass manufacturing in eastern states is in part a consequence of the early development and location of glass manufacuring in the Atlantic Seaboard states. The westward movement of production lagged behind the migration of markets and tends to become more pronounced in machine methods of production which entail high capital costs. Nevertheless the constant drive to reduce costs must eventually take into account freight rates on glass shipments. The window glass market in Chicago, for example, is supplied mainly by plants in West Virginia, Indiana, and Ohio. The weighted average transportion charge on glass to this city is 43.7 cents per hundredweight.[2] This is roughly 12 per cent of the weighted cost of production of a hundredweight of glass, an item of cost which may well count in considering the advisability of relocating glass factories nearer the Upper Mississippi Valley market.

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[2] Report to the President on Cylinder, Crown and Sheet Glass, Report No. 33, Second Series, U. S. Tariff Commission, 1932, p. 16.

In addition to the large market for glass products and the unlimited supply of glass sand in the Upper Mississippi Valley, the introduction of natural gas into northern Illinois and the East St. Louis district has made this excellent glass-making fuel available.

AGRICULTURAL LIMESTONE

The upward trend in agricultural limestone distribution continued in 1934 over that of 1933 and 1932. Although consumption of agricultural limestone in 1934 has not returned to the level of the pre-depression years, nevertheless an increase of 81 per cent over 1933 is gratifying and indicates a return to normal limestone purchases by farmers.

Detailed statistics of distribution by counties were received from producers within the State and from producers in Indiana, Iowa, and Missouri who ship agricultural limestone into Illinois. These statistics were collected in cooperation with the Midwest Agricultural Limestone Institute.

TABLE 38.—TONNAGE OF AGRICULTURAL LIMESTONE USED IN ILLINOIS DURING 1933 AND 1934 AND SHIPPED TO OTHER STATES IN 1934

(Tons marketed in each county in Illinois)

County	1933 Total	1934		
		Produced in Illinois	Produced in other States	Total
Adams	183	7,587	...	7,587
Alexander	...	...	...	...
Bond	941	1,769	...	1,769
Boone	40	1,060	...	1,060
Brown	267	918	...	918
Bureau	611	1,004	42	1,046
Calhoun	...	...	...	...
Carroll	...	...	...	...
Cass	1,715	592	...	592
Champaign	1,992	3,985	200	4,185
Christian	1,930	3,010	50	3,060
Clark	5,697	9,597	2,049	11,646
Clay	81	120	...	120
Clinton	5,430	7,937	...	7,937
Coles	519	637	895	1,532
Cook	811	2,615	...	2,615
Crawford	630	553	210	763
Cumberland	832	2,053	594	2,647
DeKalb	1,011	1,138	...	1,138
DeWitt	2,418	2,709	...	2,709
Douglas	657	786	1,391	2,177
DuPage	954	567	...	567
Edgar	1,594	1,875	1,651	3,526
Edwards	1,092	1,233	146	1,379
Effingham	2,259	1,058	3,142	4,200
Fayette	711	1,079	...	1,079
Ford	1,196	3,023	666	3,689
Franklin	1,123	2,547	...	2,547
Fulton	827	2,577	155	2,732
Gallatin	283	134	...	134
Greene	7,745	11,046	...	11,046
Grundy	657	1,483	...	1,483
Hamilton	746	1,173	...	1,173
Hancock	187	2,054	...	2,054
Hardin	300	1,200	...	1,200
Henderson	43	...	...	...
Henry	3,617	3,911	4,978	8,889
Iroquois	3,500	2,772	2,869	5,641
Jackson	3,569	5,423	...	5,423
Jasper	375	614	...	614
Jefferson	590	1,073	228	1,301
Jersey	937	5,326	...	5,326
Jo Daviess	...	102	...	102
Johnson	100	1,500	...	1,500
Kane	1,357	1,923	...	1,923
Kankakee	543	433	...	433
Kendall	2,238	2,687	...	2,687
Knox	1,091	2,555	2,241	4,796
Lake	264	1,237	...	1,237
LaSalle	487	2,339	...	2,339
Lawrence	245	326	1,198	1,524

TABLE 38.—TONS MARKETED IN EACH COUNTY IN ILLINOIS—*Continued*

County	1933 Total	1934 Produced in Illinois	1934 Produced in other States	1934 Total
Lee	92	614	...	614
Livingston	4,154	4,625	...	4,625
Logan	256	1,630	...	1,630
McDonough	237	2,667	...	2,667
McHenry	529	1,224	...	1,224
McLean	4,204	18,100	13,495	31,595
Macon	1,451	2,976	369	3,345
Macoupin	3,616	15,891	...	15,891
Madison	14,143	15,364	...	15,364
Marion	1,947	1,554	1,092	2,646
Marshall	470	972	...	972
Mason	3,438	2,352	...	2,352
Massac	200	...	...	...
Menard	609	671	...	671
Mercer	362	384	2,671	3,055
Monroe	10,910	16,521	...	16,521
Montgomery	2,465	3,236	...	3,236
Morgan	1,121	3,226	...	3,226
Moultrie	456	449	...	449
Ogle	20	...	...	...
Peoria	1,698	5,480	190	5,670
Perry	2,207	4,250	...	4,250
Piatt	610	3,099	225	3,324
Pike	...	770	...	770
Pope	350	1,260	...	1,260
Pulaski	...	100	...	100
Putnam	235	57	...	57
Randolph	13,248	16,286	235	16,521
Richland	357	414	...	414
Rock Island	2,909	1,683	1,933	3,616
St. Clair	16,884	6,362	...	6,362
Saline	3,090	5,906	280	6,186
Sangamon	1,408	4,122	...	4,122
Schuyler	457	170	...	170
Scott	402	268	...	268
Shelby	1,592	1,340	80	1,420
Stark	538	783	520	1,303
Stephenson	...	900	...	900
Tazewell	1,700	3,874	...	3,874
Union	3,950	3,100	...	3,100
Vermilion	947	1,631	805	2,436
Wabash	633	87	1,363	1,450
Warren	803	75	140	215
Washington	16,485	3,912	7,940	11,852
Wayne	301	304	150	454
White	1,317	177	1,870	2,047
Whiteside	718	2,134	32	2,166
Will	50	4,031	...	4,031
Williamson	1,338	1,915	...	1,915
Winnebago	...	500	...	500
Woodford	1,661	5,462	...	5,462
County Unknown	...	5,798	...	5,798
Total	190,963	290,046	56,095	346,141

AGRICULTURAL LIMESTONE PRODUCED IN ILLINOIS AND MARKETED IN OTHER STATES

State	Tons	
	1933	1934
Wisconsin	0	85
Iowa	62	65
Missouri	80	2,232
Kentucky	0	0
Indiana	5,299	9,093
Michigan	421	1,546
Tennessee	730	238
Total shipped from Illinois	6,592	13,259

PORTLAND CEMENT

Portland cement shipped from mills in Illinois in 1934 amounted to 3,907,000 barrels, a decline of 286,048 barrels. Value of the product was $5,489,000, an increase of $881,665 and the value per barrel increased from $1.08 in 1933 to $1.40 in 1934.

TABLE 39.—SHIPMENTS OF CEMENT, IN BARRELS, VALUE, AND CONSUMPTION IN ILLINOIS, 1928-1934 [a]

Year	Shipments	Value	Average factory value per barrel	Consumption
1928	7,405,667	$11,602,848	$1.57	17,683,269
1929	7,738,208	11,134,538	1.44	13,490,520
1930	7,951,680	10,519,162	1.32	11,164,248
1931	6,425,909	5,342,446	0.83	7,925,435
1932	5,829,687	3,446,482	0.59	5,822,358
1933	4,193,048	4,607,335	1.08	5,281,216
1934	3,907,000	5,489,000	1.40	5,008,357

[a] United States Bureau of Mines, Monthly Cement Statement No. 164

TABLE 40.—PORTLAND CEMENT CONSUMPTION IN ILLINOIS, 1933-1934 (IN BARRELS) [a]

Month	1933	1934
January	71,367	133,420
February	115,629	99,658
March	125,846	183,486
April	171,203	386,683
May	177,861	671,643
June	347,314	557,475
July	1,124,429	512,159
August	996,408	545,571
September	881,269	546,926
October	665,137	736,326
November	295,027	476,070
December	309,726	158,940
Total	5,281,216	5,008,357

[a] United States Bureau of Mines, Monthly Cement Statements.

FLUORSPAR

Expanded activity at steel mills coupled with an increase in the average quantity of fluorspar used per ton of steel made, resulted in a consumption of about 20,600 tons more fluorspar by the steel industry in 1934 than in 1933. However, this increased consumption was not accompanied by a corresponding improvement in the sales of fluorspar, which were only about 9,600 tons more than in 1933, due to withdrawal from consumers' stocks.

The total sales of fluorspar to consumers in the United States in 1934 were 101,662 short tons, of which 85,264 tons were from domestic mines and 16,398 tons were imported.

TABLE 41.—FLUORSPAR SHIPPED FROM ILLINOIS AND KENTUCKY MINES, 1930-1934[a]

Year	Shipments (tons)	Value	Average value
Illinois			
1930	44,134	$936,473	$18.95
1931	28,072	468,386	16.69
1932	9,615	156,279	16.25
1933	36,075	543,060	15.05
1934	33,234	567,396	17.07
Kentucky			
1930	39,181	836,473	18.95
1931	23,462	437,642	18.65
1932	14,975	225,052	15.28
1933	34,614	469,451	13.56
1934	43,163	690,990	16.01

[a] Data from U. S. Bureau of Mines, Mineral Market Reports, Fluorspar in 1934.

TABLE 42.—FLUORSPAR SHIPPED FROM MINES IN THE UNITED STATES, 1933-1934, BY KINDS[a]

Kind	1933			1934		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Gravel	61,216	$782,976	$12.79	74,249	$1,121,974	$15.11
Lump	2,127	34,401	16.17	3,101	60,135	19.39
Ground	9,587	221,801	23.14	8,436	209,296	24.81
Total	72,930	1,039,178	14.25	85,786	1,391,405	16.22

[a] Data from U. S. Bureau of Mines, Mineral Market Report, Fluorspar in 1934.

Stocks at mines.—The stocks of fluorspar at mines or at shipping points on December 31, 1934, consisted of 46,059 short tons of gravel fluorspar, 4,111 tons of lump fluorspar, and 416 tons of ground fluorspar, a total of 50,586 tons of "ready-to-ship" fluorspar. In addition, there was in stock piles at the close of 1934 about 33,300 tons of crude (run-of-mine) fluorspar, which is calculated to be

Table 43.—Fluorspar Shipped From Mines in the United States, 1933-1934, by Uses[a]

Use	1933			1934		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Steel	60,279	$769,889	$12.77	70,672	$1,061,864	$15.03
Foundry	1,039	13,791	13.27	1,489	23,807	15.99
Glass	6,778	147,985	21.83	7,343	167,182	22.77
Enamel and vitrolite	3,100	76,932	24.82	2,590	67,849	26.20
Hydrofluoric acid and derivatives	950	18,604	19.58	1,666	35,708	21.43
Miscellaneous	713	11,010	15.44	1,504	26,393	17.55
Exported	71	967	13.62	522	8,602	16.48
Total	72,930	1,039,178	14.25	85,786	1,391,405	16.22

[a] Data from U. S. Bureau of Mines, Mineral Market Reports, Fluorspar in 1934.

equivalent to about 14,600 tons of merchantable fluorspar. These stocks compare with 44,777 tons of "ready-to-ship" fluorspar and 42,000 tons of crude fluorspar on December 31, 1933.

Imports.—The imports of fluorspar into the United States in 1934 were 16,705 short tons (10,632 tons containing more than 97 per cent and 6,073 tons containing not more than 97 per cent calcium fluoride) compared with 10,409 tons (5,165 tons containing more than 97 per cent and 5,244 tons containing not more than 97 per cent calcium fluoride) in 1933. The imports were equivalent to 19 per cent of the total shipments of domestic fluorspar in 1934 compared with 14 per cent in 1933.

Of the imports in 1934, about 35 per cent was metallurgical-gravel fluorspar, 11 per cent ceramic-ground fluorspar, and 54 per cent acid (chiefly lump) fluorspar. The metallurgical-gravel fluorspar was imported chiefly from Spain, followed in order by Germany, Newfoundland, United Kingdom, and China; the ceramic-ground fluorspar was imported chiefly from Germany, followed in order by Spain, Italy and China; and the acid-grade fluorspar was imported chiefly from Germany, followed in order by the Union of South Africa, Newfoundland, and Spain.

Table 44 shows the imports of fluorspar into the United States by countries in 1933 and 1934.

Table 45, compiled from data furnished by importers to the Bureau of Mines, shows the quantities of imported fluorspar delivered to consumers in the United States in 1933 and 1934 and the selling price at tidewater, duty paid, irrespective of the year of importation into the United States; it differs from the preceding table, which shows the quantities received in the United States during 1933 and 1934. The quantities given in the next table are based on the actual out-turn weight on which duty was paid and the entries were liquidated.

TABLE 44.—FLUORSPAR IMPORTED INTO THE UNITED STATES, 1933-1934, BY COUNTRIES[a]

Country	1933		1934	
	Short tons	Value	Short tons	Value
Canada[b]	....	....	187	$ 2,962
China	27	$ 413	112	990
France	204	1,247	....	....
Germany	4,333	54,836	8,224	98,565
Italy	534	4,533	60	587
Newfoundland	320	2,646	745	10,460
Spain	4,261	28,690	4,914	35,316
Union of South Africa	713	12,449	1,997	31,872
United Kingdom	17	229	466	2,534
	10,409	105,043	16,705	183,286

[a] Data from U. S. Bureau of Mines, Mineral Market Reports, Fluorspar in 1934.
[b] Fluorspar imported from Canada originated in Newfoundland.

TABLE 45.—IMPORTED FLUORSPAR DELIVERED TO CONSUMERS IN THE UNITED STATES IN 1933 AND 1934

	1933			1934		
	Short tons	Selling price at tide-water, including duty		Short tons	Selling price at tide-water, including duty	
		Total	Average		Total	Average
Steel	6,208	$105,800	$17.04	5,394	$100,830	$18.69
Glass	1,288	33,160	25.75	1,257	36,120	28.74
Enamel	939	24,953	26.57	583	17,324	29.72
Hydrofluoric acid	3,971	90,313	22.74	8,982	217,650	24.23
Cement	....	....	....	182	4,100	22.53
Total	12,406	254,226	20.49	16,398	376,024	22.93

OTHER NON-METALLIC PRODUCTS

Detailed statistics of the use of sand, gravel, and limestone are given in Table 46, presented by districts as shown in figure 4. The decline in production which the industry has experienced since 1929 has been arrested and some of the uses of these non-metallics are again showing an upward trend.

TABLE 46.—PRODUCTION OF SAND AND GRAVEL AND LIMESTONE IN ILLINOIS BY DISTRICTS, 1932-1934

District Number (See Fig. 4)	1932		1933 [a]		1934 [a]	
	Tons	Value	Tons	Value	Tons	Value
Structural Sand						
I, II	332,486	126,317	242,395	114,680	409,945	131,288
III	148,380	61,189	123,767	58,830	214,153	136,076
IV	164,623	78,680	162,989	86,923	149,468	99,726
V	64,108	28,572	170,774	57,446	171,947	88,361
VI	33,956	10,132	24,443	7,973	6,530	5,206
Paving and Roadmaking Sand						
I, II	436,432	67,489	373,432	165,393	443,465	135,277
III	321,026	97,637	114,351	58,522	158,617	112,636
IV	392,388	159,931	311,061	156,236	268,313	130,162
V	135,588	58,905	191,587	60,341	131,000	63,800
VI	131,630	52,403	94,677	46,970	66,494	43,371
Structural Gravel						
I, II	446,665	179,678	246,330	122,369	516,740	178,502
III	188,693	92,368	124,107	62,809	248,688	160,979
IV	216,780	121,039	187,030	112,679	142,346	87,263
V	([b])	([b])	([b])	([b])	([b])	([b])
VI	17,884	10,049	15,774	10,507	20,016	10,359
Paving and Roadmaking Gravel						
I, II	1,164,801	461,497	730,143	336,305	689,622	243,690
III	509,921	253,704	215,251	110,171	295,436	160,138
IV	481,033	220,246	598,578	308,790	431,623	184,239
V	([b])	([b])	([b])	([b])	([b])	([b])
VI	122,638	57,494	104,819	70,333	60,363	49,336
Railroad Ballast Sand and Gravel						
I, II	534,019	140,828	246,640	102,784	361,503	151,084
III	70,170	10,563	16,660	8,290	5,630	2,815
IV	128,706	25,000	116,540	43,966	35,774	17,020
V	....	....	....	....	....	....
VI	([b])	([b])	([b])	([b])	([b])	([b])
Other Sand and Gravel						
I, II	5,400	2,201	24,711	8,430	17,741	8,371
III	620,643	748,165	776,302	959,725	979,132	1,250,560
IV	17,864	14,461	28,762	21,836	20,028	22,703
V	16,025	8,780	([b])	([b])	([b])	([b])
VI	16,695	10,745	37,517	15,949	39,132	24,649
Total Sand and Gravel						
I, II	2,901,053	1,039,552	1,862,651	852,481	2,590,100	848,212
III	1,858,833	1,263,599	1,370,438	1,258,347	1,901,656	1,823,204
IV	1,420,144	623,107	1,404,960	730,430	1,047,552	541,113
V	233,174	111,199	379,462	130,998	329,686	170,089
VI	338,120	146,950	299,274	161,189	225,154	148,234
Illinois	6,751,324	3,184,407	5,316,784	3,133,445	6,094,148	3,530,852

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[a] Commercial producers only.

[b] Concealed in total. Less than three producers.

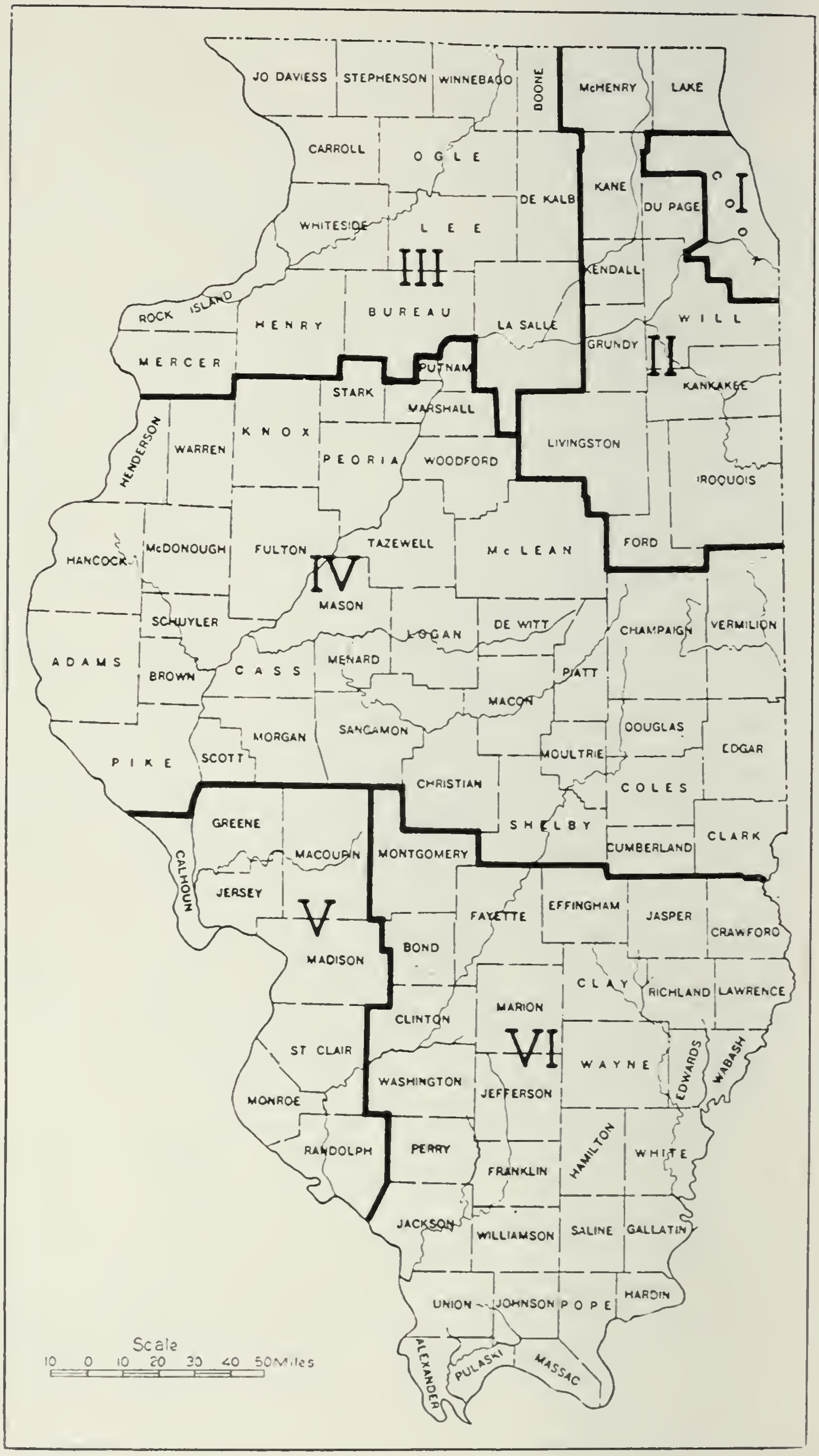

Fig. 4.—Index Map of Illinois Showing Location of Districts According to Which Production of Sand and Gravel and Limestone (Table 46) is Given

TABLE 46.—*Continued*

District Number (See Fig. 4)	1932		1933 [a]		1934 [a]	
	Tons	Value	Tons	Value	Tons	Value
			Road Metal and Concrete			
I	1,047,230	576,057	702,241	403,662	1,102,415	693,510
II	517,255	365,548	410,816	290,973	515,687	370,156
III	91,410	82,855	45,142	36,000	119,533	109,939
IV	55,787	69,805	47,563	51,855	183,668	189,177
V	390,492	277,337	462,142	334,401	641,903	502,272
VI	174,950	145,800	91,582	84,647	104,036	98,349
			Railroad Ballast			
I	69,764	42,630	(b)	(b)	96,467	51,234
II	58,833	41,718	64,753	47,693	119,648	89,633
III	....	....			....	....
IV	(b)	(b)	....	....	....	....
V	25,813	17,796	(b)	(b)	(b)	(b)
VI	(b)	(b)	(b)	(b)	(b)	(b)
			Agricultural Limestone			
I	39,144	23,895	36,750	22,350	48,400	30,650
II	15,026	11,276	40,812	22,279	76,600	48,661
III	11,396	9,788	9,903	10,875	10,824	9,173
IV	15,380	21,061	14,621	17,434	59,543	47,208
V	65,919	58,222	104,818	75,651	223,596	131,267
VI	7,944	8,020	14,346	12,533	29,845	24,802
			Flux			
I	83,589	49,874	130,800	71,880	251,800	142,250
II	....	....	....	....	....	....
III	....	....	....	....	....	....
IV	(b)	(b)	(b)	(b)	1,088	1,584
V	60,794	65,909	(b)	(b)	(b)	(b)
VI	....	....	....	....	....	....
			Rubble and Rip Rap			
I	20,875	22,625	19,450	19,200	(b)	(b)
II	(b)	(b)	(b)	(b)	(b)	(b)
III	....	....	(b)	(b)	(b)	(b)
IV	(b)	(b)	(b)	(b)	25,186	15,258
V	138,900	105,433	84,880	89,618	124,507	122,876
VI	(b)	(b)	(b)	(b)	(b)	(b)
			Miscellaneous Limestone			
I	25,336	56,765	(b)	(b)	(b)	(b)
II	(b)	(b)	(b)	(b)	(b)	(b)
III	(b)	(b)	(b)	(b)	(b)	(b)
IV	7,574	23,421	(b)	(b)	8,949	25,321
V	8,249	24,145	9,774	37,544	7,296	26,470
VI	....	....	....	....	....	....
			Total Limestone			
I	1,285,938	771,846	954,541	557,492	1,618,389	1,029,048
II	598,358	424,547	523,362	355,328	718,100	518,873
III	103,056	92,753	55,725	49,450	131,627	126,624
IV	81,775	117,752	70,987	94,457	278,434	278,548
V	690,267	548,842	682,767	551,580	1,013,370	796,724
VI	205,914	177,342	109,979	100,943	141,640	131,834
Illinois	2,965,308	2,133,082	2,397,361	1,709,250	3,901,560	2,881,651

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[a] Commercial producers only.
[b] Concealed in total. Less than three producers.

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HENRY HORNER, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 40

THE GEOLOGY AND OIL AND GAS POSSIBILITIES OF PARTS OF MARION AND CLAY COUNTIES

With a Discussion of the Central Portion of the Illinois Basin

BY

J. MARVIN WELLER AND ALFRED H. BELL

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THE GEOLOGY AND OIL AND GAS POSSIBILITIES OF PARTS OF MARION AND CLAY COUNTIES

With a Discussion of the Central Portion of the Illinois Basin

J. MARVIN WELLER AND ALFRED H. BELL

CHAPTER I

SUMMARY OF CONCLUSIONS

Stratigraphic and structural studies of outcropping Pennsylvanian strata have revealed the presence of closed structures in eastern Marion and western Clay counties, Illinois. It seems probable that at least two of four closed structures described herein extend into the deeper strata and that they may have caused accumulation of oil and gas in some of these strata.

Available data indicate that the following territory is located on the higher parts of these structures:

(1) **Louisville anticline:** Secs. 23 and 24, N. ½ sec. 25, T. 4 N., R. 5 E.; S. ½ sec. 19, N. ½ sec. 30, T. 4 N., R. 6 E., Clay County.
(2) **Omega anticline:** SW. part of sec. 5, secs. 6 and 7, W. ½ sec. 8, W. ½ sec. 18, T. 3 N., R. 4 E.; E. part sec. 1, secs. 12, 13, and 24, E. ½ sec. 23, T. 3 N., R. 3 E., Marion County.
(3) **Xenia dome:** sec. 23, E. ½ sec. 22, W. ½ sec. 24, T. 3 N., R. 5 E., Clay County.
(4) **Iola dome:** S. part sec. 6, NW. part sec. 7, T. 4 N., R. 5 E., Clay County; E. part sec. 12, T. 4 N., R. 4 E., Marion County.

Sandstones in the Lower Chester strata are productive in the Sandoval and Carlyle fields 10 miles west of the area mapped in figure 4, and in the Lawrence County field 50 miles east of this area. These and deeper strata have not been tested in the area described. A favorable indication is the showing of oil found in the Benedum-Trees Oil Company Harrell well, sec. 27, T. 4 N., R. 5 E., Clay County (datum point No. 30) in a sandstone in the middle part of the Chester series (Fig. 4). This test was located high on the Louisville anticline.

Because of lack of outcrops the structure in parts of the area mapped is not known in detail, and for this reason it is recommended that the known information be supplemented by shallow test drilling or by geophysical surveys, or both, prior to the location of deep tests for oil and gas.

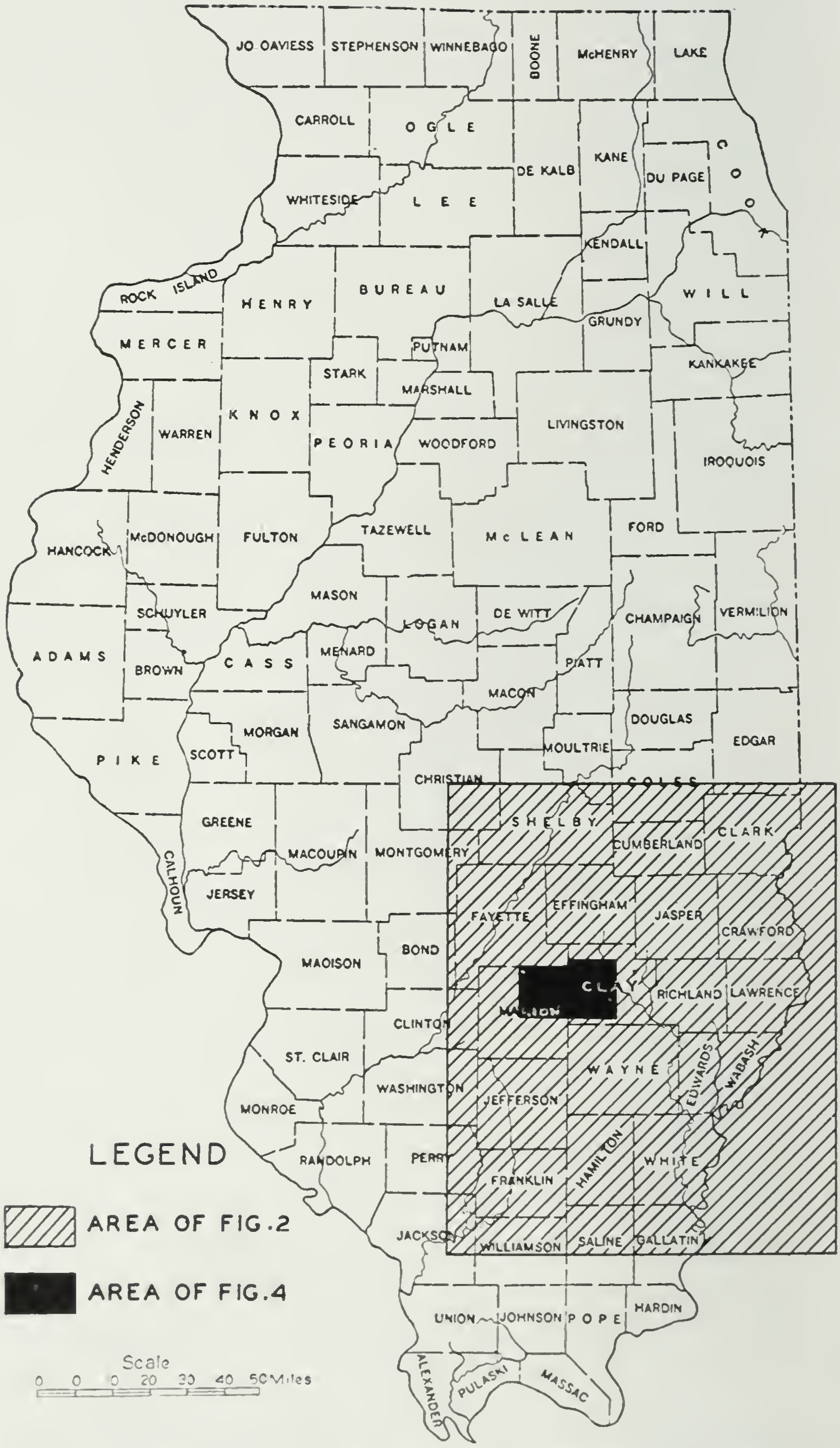

Fig. 1.—Index map showing location of areas mapped in figures 2 and 4.

CHAPTER II

INTRODUCTION

GENERAL STATEMENT

For several years the Illinois State Geological Survey has been carrying on a state wide investigation of Pennsylvanian stratigraphy. This study has revealed the presence of structures that appear favorable for the accumulation of oil and gas. Although the investigation is not yet completed, it seems desirable to publish the available data regarding the most promising of the favorable structures found so far, especially in view of the recent revival in interest in the search for new oil and gas fields.

The discovery of oil in 1927 in the Mt. Pleasant district in Michigan, located centrally in a structural basin that is comparable in extent to the structural basin of Illinois, and the subsequent development there of the most important oil field in Michigan, has led to a new interest in the oil prospects of the Illinois Basin. The structural features herein described in eastern Marion County and western Clay County are located not far from the deepest part of the Illinois Basin (Figs. 1 and 2).

The central part of the Illinois Basin and the LaSalle anticline which delimits it to the east are structural features which have long been known as a result of deep drilling. However, recent stratigraphical studies of the Pennsylvanian system in Illinois, by J. Marvin Weller, have revealed that the structure of the surface beds does not correspond to the structure of the pre-Pennsylvanian formations. Throughout about a dozen counties lying south of Clark County and east of the Third Principal Meridian an extremely limited stratigraphic section of upper Pennsylvanian beds outcrops. The surface beds of this region are, therefore, if viewed broadly, practically horizontal although in this same area the underlying Mississippian rocks possess a structural relief of over 2500 feet.

As shown by elevations on the base of the Pennsylvanian system, somewhat less than half of this structure was produced by post-Mississippian pre-Pennsylvanian folding and the remainder probably resulted from numerous comparatively small warpings distributed at intervals throughout early Pennsylvanian time. Although subsidence of the Illinois Basin as a whole probably continued to some extent throughout later Pennsylvanian time no important accentuation of the LaSalle anticline south of the Martinsville dome in Clark County was accomplished nor has post-Pennsylvanian movement, which raised the Ozark region to the westward and the Cincinnati arch to the eastward, affected the southern portion of the LaSalle anticline.

Although the surface beds in the central part of the Illinois Basin are practically horizontal in a regional sense, gentle dips, variously directed, are the rule. Because of irregular depositional conditions during Pennsylvanian time, many of the beds, particularly the clastic ones, thicken and thin irregularly and more or less rapidly, and contours drawn upon any two horizons will not correspond. Therefore, it should not be assumed that the common gentle dips of any one bed are the result of diastrophic structure or that they might be expected to persist beneath the surface; they are more likely to have been produced by original inequalities of deposition or by subsequent differential compaction.

There are, however, areas within the basin where steeper, more or less local dips, or gentle dips of more than usual constancy suggest that actual structural conditions may be reflected. If so, it is possible that the magnitude of these surface structures will increase considerably with depth. The region considered in this report is one of the most noteworthy of these areas.

The mapping of structures in the central part of the Illinois Basin is dependent upon the identification and correlation of Pennsylvanian rocks. Because there is no publication adequately describing the Pennsylvanian stratigraphy of the central part of the Illinois Basin and because the strata outcropping in Marion and Clay counties are also exposed at many places in adjoining counties, the stratigraphy of this area is considered in some detail in the following pages. The more important beds are informally referred to by tentative names, mainly lithologic, and present conclusions regarding their correlation are stated (Fig. 5). Field work has not yet been completed in this part of the State, however, and it must be emphasized that future field studies may necessitate changes in these correlations.

LEASING BY OIL COMPANIES

During the time of preparation of this report geological field work in portions of the Illinois Basin has been carried on independently by certain oil companies, and on the basis of such information independently gained, some of the territory discussed herein is now under lease.

ACKNOWLEDGEMENTS

Mr. W. A. Newton of the State Geological Survey assisted in the stratigraphic studies, and Messrs. P. S. McClure and W. C. Imbt of the Survey staff, carried on the instrumental leveling and mapping, by plane-table and alidade, of outcrops and wells in the area shown in figure 4.

CHAPTER III

STRUCTURE AND OIL POSSIBILITIES

ALFRED H. BELL

SUBSURFACE STRUCTURE

Prospecting for petroleum in the Illinois Basin area is hampered by lack of knowledge of the subsurface stratigraphy and structure. The coal strata which are used elsewhere in the State as structural key horizons, especially Herrin (No. 6) coal which is used in most of southwestern Illinois, cannot be definitely traced at present into the deeper parts of the basin. Even less is known of the lower Pennsylvanian and of the pre-Pennsylvanian rocks. There is at present no known structural key horizon within the Pennsylvanian system which can be used throughout the basin area. However, the position of the pre-Pennsylvanian unconformity can be recognized in some well logs, especially where sets of sample cuttings are available, and by correlation this horizon can be recognized with some degree of assurance in most driller's logs of wells from which no samples are available.

Contour map on pre-Pennsylvanian unconformity.—By plotting the elevation of the base of the Pennsylvanian strata wherever the data were available, it has been possible to construct a very generalized contour map of the base of the Pennsylvanian (Fig. 2). Although not strictly a structure map because it depicts a surface of unconformity, this map does present a generalized picture of the form of the basin. It is subject to correction in detail when additional subsurface data become available.

All of the wells shown in figure 2 provide data on the base of the Pennsylvanian system. All but three of them actually reach that horizon; in the remaining three the depth to it is estimated by correlation with other logs. (Table 1.) Wells which were too shallow or too poorly logged to provide data on the base of the Pennsylvanian system are not included on the map, which is therefore not a complete dry-hole map.

Those interested in obtaining all available data on drilling in specific areas may do so by communicating with the Chief, Illinois State Geological Survey, Urbana, Illinois.

TABLE 1.—WELL DATA TO ACCOMPANY CONTOUR MAP ON BASE

Map No.	Location					Company
	County	Location in section	Sec.	T.	R.	
1	Clay	SW.SE.NE	9	5N.	6E.	Clay Oil Corporation
2		NE. corner	27	4N.	5E.	Benedum Trees and Grayson
3		SE. NW.	15	3N.	5E.	Benedum Trees
4		NE. SW.SE	8	2N.	7E.	Amber Oil Company
(*b*) 5	Clinton	NW. corner	36	2N.	1W.	Ohio Oil Company
6	Crawford	NE. SW	23	8N.	14W.	O. C. Sutherland
7		NE.SE.NE	12	7N.	14W.	Associated Producers
8		SE.NW	25	7N.	13W.	Ellison et al
(*b*) 9		S.cen.SE.NW	22	7N.	12W.	D. C. Jones
10		SE.SW.NE	24	7N.	11W.	Stevens, Karnes
11		Near center	12	6N.	13W.	Zahnizer
12		S.cen.NE.SW	26	6N.	13W.	Fred Patchel
13		SE.SW.SE	13	5N.	13W.	Silurian Oil
14		NW.SE.SE	23	5N.	12W.	Jessup et al
15		N.cen.NW.NW.	3	5N.	11W.	W. C. McBride
16	Cumberland	SW.NE	13	10N.	10E.	Ohio Oil Company
17		SE.SW.NE	16	10N.	8E.	Central Illinois Petroleum Company
18		NE.NE.NE	11	9N.	10E.	Pure Oil Company
19		SW.NE.SW	14	9N.	10E.	Petroleum Exploration
20	Edwards	NW.SE.SW	31	1N.	11E.	Ohio Oil Company
21		SW.NW.NW	3	2S.	10E.	Leach Brothers
22	Effingham	SW.SW.NW	16	8N.	7E.	W. C. Kremer
23		NW.SW.SW	20	7N.	4E.	Stockholders Oil and Gas
24	Fayette	NE.NW	22	9N.	1W.	?
25		?	?	7N.	3E.	?
26		?	13	6N.	2E.	Ohio Oil Company
27		?	36	6N.	1W.	Vandalia Oil and Gas Company
28		SW.SW.SW	28	5N.	1E.	Big 4 Oil and Gas Company
29	Gallatin	NE.NE.SE	27	7S.	8E.	Omaha Oil and Gas Company
30		SW.SW	32	7S.	8E.	?
31		NW.NW.SE	31	9S.	9E.	C. T. Pierce
32	Hamilton	NE.NE.NE	4	6S.	6E.	C. A. Morrison
33	Jasper	?	4	8N.	14W.	Pure Oil Company
34		NE.NW.SW	15	8N.	14W.	?
35		NE.SE.NE	6	6N.	10E.	Federal Royalty Company and Bayou-Teche Oil Company
36		NE.SE.NW	7	6N.	9E.	Richard Eke
37		SW.SW.NW	23	6N.	9E.	Newton Oil Company
38	Jefferson	NE.SW.NW	8	1S.	3E.	Pure Oil Company
39		NE.SW.SE	17	1S.	2E.	Busch-Everett
40		SW.SW.NW	4	1S.	1E.	Ohio Oil Company
41		NW.SW	6	1S.	1E	Roleum
42		SW.SE.NW	32	2S.	2E.	Shiloh Oil Company
43		SE.NW.NW	17	3S.	4E.	Opdyke Oil Company
44		NW.NW.SE	24	4S.	2E.	Phillips Petroleum Corp.
45		NE.NW.NE	16	4S.	3E.	E. R. List

See p. 15 for footnotes.

of Pennsylvanian System, Datum Sea-Level (Fig. 2)

Farm	Total depth (feet)	Curb elevation (feet)	Source (*a*)	Base of Pennsylvanian	
				Depth (feet)	Elevation (feet)
Williams	2387	441	E	1981	—1540
J. H. Harrell	2302	534	A	1900	—1366
C. Anderson	2076	541	A	1930	—1389
Curry	2401	431	A	2130	—1699
L. Thierer	1685	485	A	975	—490
Matheny	1256	530±	F	1000	—470±
Comly No. 7	1518	500	A	1013	—513
M. K. Coulter	1332	534	F	1332+	—798—
C. E. Davis	1330	551	A	1225	—674
Walker	1451?	435±	B	1088	—653±
Jones	4620	525	F	1377±	—852±
Shipman No. 5	1388	496	A	1122±	—626±
Petty No. 1	1497	432	G	1330	—898
Conover	1795	550±	C	1340	—790±
Oldham	1731	530	G	1315	—785
E. Chrysler	1913?	624	A	640	—16
Dobbs	2315	630±	D	1555	—925±
A. M. Philips	1050	623	A	950	—327
O. D. McFarlin	1532	620±	D	1262	—642±
Fullerton	2754	507	A	2350	—1843
Jos. Ellen	(*c*) 4785	510±	D	2504	—1994±
D. Ordner	1830	610±	D	(*d*) 1940	—1330±
H. Radloff	2052	620±	D	1550	—930±
A. Aylward	2825	651	A	1170	—519
St. Elmo	1300	618±	C	(*d*) 1450	—832±
G. A. Parks	1610	560±	D	1365	—805±
Thos. Inman	2961	530±	D	1280	—750±
G. W. Albert	1841	510	B	1172	—662
M. M. Davis	1790	370	C	1620	—1250
W. D. Forester	1807	350	C	1510	—1160
Drone	3612	355	C	855	—500
F. Pitman	2564	445	A	1915	—1470
A. Leamon	1417	580±	D	1010	—430±
1st State Bank	1382	540±	D	1040	—500±
C. F. Ross	2202	500±	C	2065	—1565±
R. Klier	(*e*) 2540	540±	D	2291	—1751±
?	2583	550±	D	2138	—1588±
Wm. Meyers	1930	530	D	1733	—1203
Talbot	2020	521	A	1725	—1204
G. P. Baldridge	1831	575	A	1665	—1090
M. Hardy	1668	532	A	1300	—768
C. Mannen	1940	458	C	1685	—1227
R. I. Estes	2370	523	A	2020	—1497
Moss	2928	417	A	1694	—1277
Knowles	2028	448	A	1834	—1386

See p. 15 for footnotes.

Table 1 *Concluded.*—Well Data to Accompany

Map No.	Location					Company
	County	Location in section	Sec.	T.	R.	
46	Lawrence	SW.SW.NW.	19	4N.	10W.	Shell Petroleum
47		Cen. NE.NE.	35	5N.	13W.	Ohio Oil Company
48		SW.SW	17	4N.	12W.	Ohio Oil Company
49		NW.SE.NW.	29	4N.	12W.	W. C. McBride
(*b*) 50		NE. corner SW.	7	3N.	12W.	Ohio Oil Company
51		SW.SE.	20	3N.	12W.	Big Four Oil and Gas Company
52		SE.SW.SE.	25	3N.	12W.	Associated Producers
53		NE.SE.NW.	23	2N.	12W.	Risely et al.
54	Marion	NE.NW.SW.	6	4N.	3E.	Southwestern Oil and Gas.
55		NW.SE.	20	4N.	2E.	Riggs
56		NE.SE.	9	4N.	1E.	Ohio Oil Company
57		SE.SW.	20	4N.	1E.	Riggs
58		SW. corner	16	3N.	1E.	Ohio Oil Company
59		NW.SW.	17	3N.	1E.	F. J. Casey
60		SW.NE.	27	3N.	1E.	Ohio Oil Company
61		SW.SE.	35	3N.	1E.	E. R. Steiner and A. H. Gibson
62		SE. corner	25	3N.	4E.	Ohio Oil Company
63		SW.SE.	4	2N.	4E.	Kelley and Finn
64		NW.SE.NW.	24	2N.	3E.	Kelley and Finn
65		SW.NE.	33	2N.	2E.	Lorenzen
(*b*) 66		SW.SW.	28	2N.	1E.	Ohio Oil Company
67		SE.NW.	8	2N.	1E.	Treat-Crawford
68		NE.SW.NW.	30	1N.	1E.	Petro. Oil and Gas Company
69		NE.NW.	16	1N.	1E.	Centralia Oil Company
70		SE.NE.	16	1N.	3E.	Benoist and Finn
71	Perry	SW.NW.	5	6S.	1W.	J. H. Forester
72	Richland	NW.SE.SW.	28	4N.	14W.	P. E. Hill
73	Saline	NW.NE.SW.	28	8S.	7E.	Epi Denno Medicine Company
74		NE.SW.NE.	22	9S.	7E.	Cottage Oil Company
75		NE.SW.NE.	11	10S.	6E.	Saline County Oil Company
76	Shelby	SW.SW.SW.	19	12N.	5E.	Big 4 Oil and Gas Company
77		SE.SW.	8	11N.	4E.	W. E. Eddy
78		NE.NW.NE.	3	11N.	6E.	A. M. Myers
79		SE.SW.NE.	25	10N.	4E.	A. L. Ginther
80		NE.SW.SW.	34	10N.	4E.	?
81	Wabash	NE.SE.NW.	14	1N.	12W.	Karnes and Miller
82		SW.SE.SW.	1	1S.	13W.	Forman and Miller
83	White	NE.NE.NW.	18	7S.	10E.	Byrd Company
84	Williamson	NE.NE.NW.	12	8S.	3E.	Madison Coal Corporation.
(*b*) 85	Gibson, Indiana.	?	10	3S.	12W.	?
(*b*) 86	Knox, Indiana.	NW.	35	1N.	12W.	Eastern Gulf Oil Company.
(*b*) 87	Posey, Indiana.	NW.NW.SW.	28	4S.	13W.	Smith et al.
(*b*) 88		?	7	7S.	13W.	Wolf and Harlem
(*b*) 89		?	2	8S.	14W.	W. E. Hastings well
(*b*) 90		?	33	6S.	12W.	Hagemann drillings
(*b*) 91	Union, Kentucky.	1 mile S. of Spring Grove				?

See p. 15 for footnotes.

Contour Map on Base of Pennsylvanian System

Farm	Total depth (feet)	Curb elevation (feet)	Source (*a*)	Base of Pennsylvanian	
				Depth (feet)	Elevation (feet)
A. and M. Lohr	1717	431	F	1287	—856
N. J. Updike No. 21	1645	435	F	1305	—870
Westall No. 11	1440	435	F	1155	—720
Bowers and Ross No. 7	1631	449	A	1110	—661
W. B. Gray No. 2	2000	486	F	1485	—999
A. Gray	2059	465	F	1561	—1096
J. F. Snyder	1805	454	F	1305	—851
Brooks	2083	471	B	1490	—1019
Morris	1918	543	A	1370	—827
Oglesby	1740	536	A	1270	—734
L. F. Green	1633	514	G	1050	—536
Chandler	1640	470	D	1000	—530
Carrigan	1622	489	(B or E)	970	—481
Gerrish	1600	480	(B or E)	1000	—520
Sebastian	2280	531	(B or E)	1082	—551
Joe Cannon	1680	520	C	1080	—560
H. Henninger	2213	522	A	1910	—1388
Wooldridge	1780	473	A	1685	—1212
Williams	2236	511	A	1807	—1296
Lorenzen	1750	552	A	1520	—968
Guthrie	1625	487	A	1275	—788
A. E. Benoist No. 1	1566	518	A	960	—442
Frazier	1500	508	F	1103	—595
Brown	1667	504	A	1460	—956
Finn	2056	581	A	1825	—1244
J. H. Forrester	(*f*) 3316	465	C	502	—37
P. and H. Kocher	2481	562±	C	2332	—1770
Sutton	1818	378	B	1420	—1042
W. J. Clark	3350	360±	C	1265	—905
Herrick	1655	365±	C	1090	—725
Horn	1930	570±	D	1390	—820
W. E. Eddy	1535	563	A	1400	—837
W. O. Storm	1202	720±	D	(*d*) 1690	—970
W. Prosser	1630	620	A	1580	—960
Wm. Hoagland	1505	595	A	1500	—905
Price No. 3	2055	440	A	1480	—1040
O. Ginther No. 2	2621	486	B	1859	—1373
Byrd	2232	347	A	1759	—1412
?	2136	434	G	1657	—1223
B. F. Benson	2372	500±	H	1661	—1161±
Wm. Steckler No. 1	2286	400±	C	1535	—1135±
C. Manchette	2017	440±	C	1675	—1235±
?	1853	434	H	1730	—1296
?	1816	360	H	1750	—1390
?	1963	485	H	1580	—1095
Sol Blue No. 2	5955	350±	C	1725	—1375±

See p. 15 for footnotes.

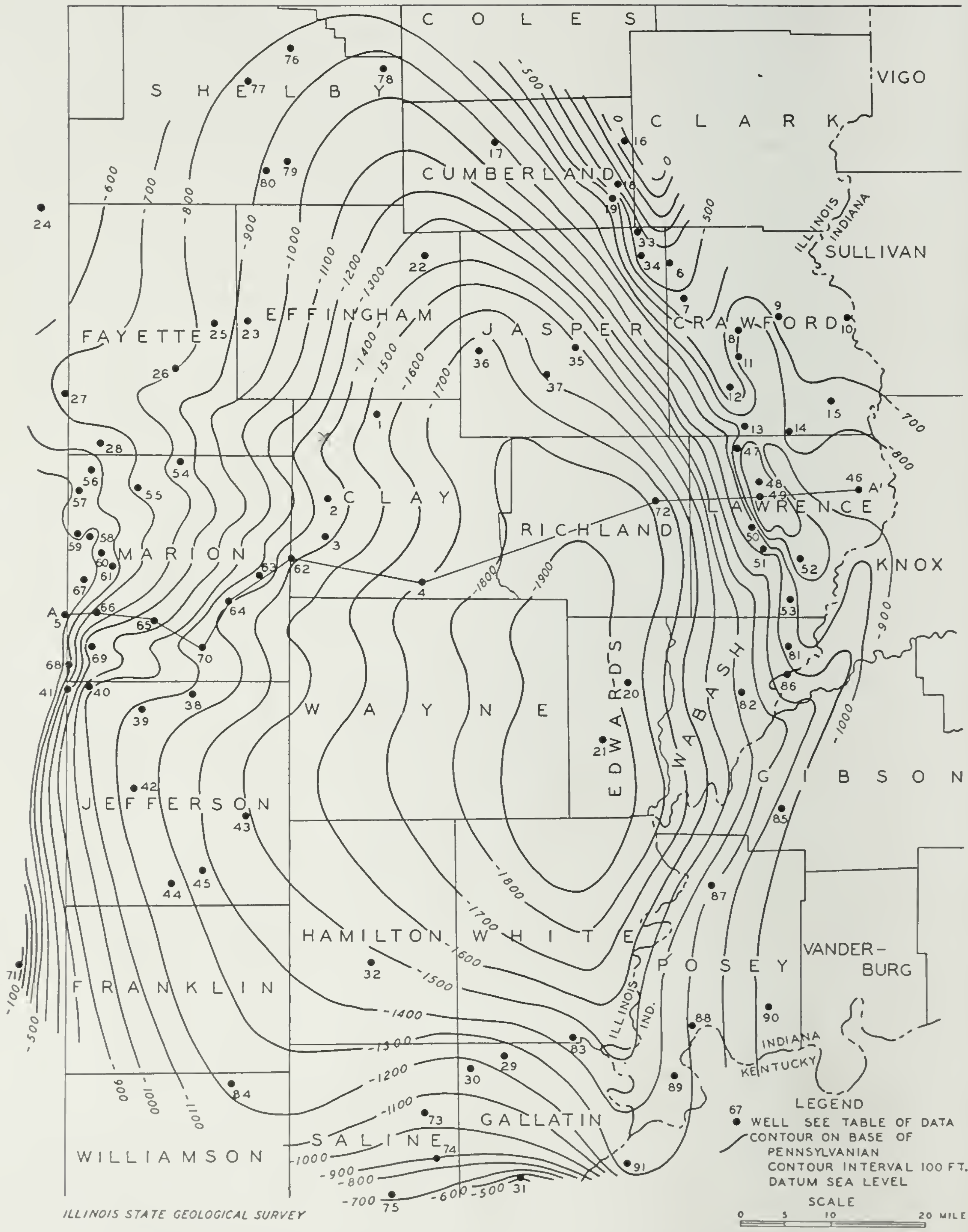

Fig. 2.—Central portion of Illinois Basin. Subsurface contour map on the base of the Pennsylvanian system, a surface of unconformity. Only those wells are shown in which the base of the Pennsylvanian can be recognized or estimated.

The Centralia-DuQuoin monocline is shown extending southward from southwest Marion County and the LaSalle anticline is conspicuous in the northeastern part of the map. Oil fields are located on both of these structures and are described in publications of the Illinois State Geological Survey.

The feature of most importance in connection with the present report is the anticlinal nose located in northern Marion County and Clay County, the axis of which apparently extends from a point about 6 miles north of the Sandoval oil field (around map No. 67, Fig. 2) eastward beyond Louisville, the county seat of Clay County. Although the details of this anticlinal nose are largely unknown, the available data seem to leave little doubt as to its existence in the approximate position shown.

Cross-section.—An east-west cross-section across the basin is shown in figure 3. This shows the relatively steep dips of the Centralia monocline on the west and the LaSalle anticline on the east, with the deeper part of the basin between. Because of lack of subsurface data, already noted for this area, the beds are shown with gentle even dips, but this is surely not the true condition. It is very likely that several folds exist in the path of this cross-section which could be shown if adequate subsurface data were available. The cross-section illustrates an interpretation of the general form of the basin and also some of the difficulties of correlation due to lack of data.

Present correlation of Chester formations shown in the cross-section suggest that post-Chester pre-Pennsylvanian warping may have been important. Data from future drilling should throw more light on this problem.

Causes of local highs and lows in pre-Pennsylvanian unconformity.—The irregularities of the unconformity at the base of the Pennsylvanian system, are the result of two factors, first deformation and erosion of the pre-Pennsylvanian strata previous to the deposition of the sediments that now lie above, and second, subsequent warping by diastrophic movement.

The major relief of the pre-Pennsylvanian unconformity, which is more than 2.000 feet between the center and edges of the basin, is undoubtedly due to diastrophism but local "highs" or "lows" having a relief of the order of

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Footnotes to Table 1, pp. 10-13:

(*a*) Source of elevation:

A—Determined by plane-table and alidade by State Geological Survey.
B—Determined by telescopic handlevel by State Geological Survey.
C—Estimated from U. S. Geological Survey topographic map.
D—Estimated from Rolfe topographic map.
E—Determined by aneroid.
F—Well in or near oil field; elevation estimated from elevations of nearby wells determined by instrument.
G—Instrumental elevation furnished by company.
H—Elevation published by Indiana Geological Survey.

(*b*) Logs published:

5 Ill. State Geol. Survey Bull. 24, pp. 73-77.
9 Ill. State Geol. Survey Bull. 2, p. 62.
50 Ill. State Geol. Survey Bull. 24, pp. 123-129.
66 Ill. State Geol. Survey Bull. 24, pp. 77-81.
85 Subsurface strata of Indiana, p. 191.
86 Illinois Petroleum No. 12, pp. 13-15 (driller's log); depth of base Pennsylvanian according to unpublished sample study log by L. E. Workman and M. A. Blair.
87 Subsurface strata of Indiana, p. 653.
88 Subsurface strata of Indiana, p. 652.
89 Subsurface strata of Indiana, p. 652.
90 Subsurface strata of Indiana, p. 651.
91 Oil and Gas in Western Kentucky, pp. 441-450.

(*c*) Drilling January 17, 1936.

(*d*) Bottom of Pennsylvanian was not reached but its depth was estimated by correlation with other logs.

(*e*) Fishing for tools, January 21, 1936.

(*f*) Drilling January 15, 1936.

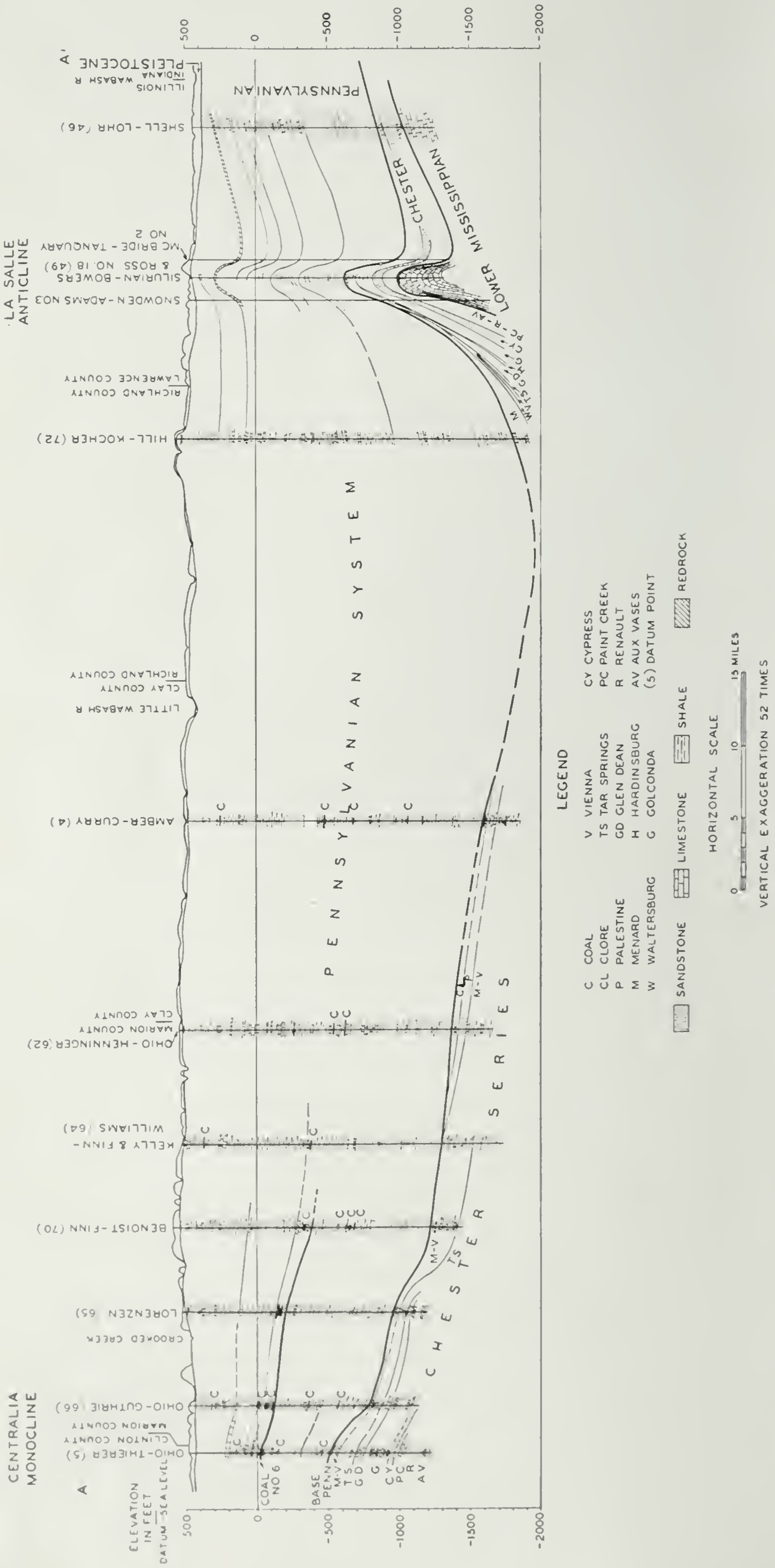

Fig. 3.—East-west cross-section A-A' across the Illinois Basin. For location of wells, see figure 2.

100 or 200 feet may be due, at least in part, to pre-Pennsylvanian erosion. Available subsurface data are insufficient to determine the relative importance of these two factors in the formation of the local "highs" and "lows."

It is altogether likely that downwarping of the basin area took place during Pottsville time, perhaps continuing later in diminished degree. However, in areas where upwarping of the surface Pennsylvanian beds coincides in location with a "high" in the pre-Pennsylvanian surface, it seems reasonable to assume that this "high" is the result of structural disturbance later in age than the surface Pennsylvanian beds. Such a condition appears to exist in eastern Marion and western Clay counties—the area described in this report.

SURFACE STRUCTURE

Introduction.—The structure of the upper Pennsylvanian beds in parts of western Clay and eastern Marion counties, and a generalized stratigraphic section of the outcropping beds is shown in figure 4. The stratigraphy and correlation of the outcropping beds is discussed below.

In using the structure contour map it should be noted that in large areas of the map there are no outcrops and the lack of knowledge of structure in these areas and the authors' interpretations are indicated by broken contour lines. Wherever the structural key horizon is not exposed, there is uncertainty as to the amount of the interval from the outcropping bed to the key bed, and in the same degree, uncertainty as to the elevation of the key bed. Where the distances between outcrops are great, as they are in that part of the area to the west of the line between ranges 3 and 4 E. (the vicinity of Kinmundy and westward), there is considerable doubt as to the correlation, and the interpretation of structure shown in this area is highly conjectural although based on careful consideration of the data now available.

Four areas of structural closure are shown (Figure 4). The north portion of another possible closure is shown in the west part of the area, but owing to lack of data, structural contours could not be drawn to the south. The four structural closures have been named the Louisville anticline, the Omega anticline, the Iola dome, and the Xenia dome.

Louisville Anticline.—The best defined structural feature in the area and perhaps the most favorable for oil and gas prospecting is the anticline which lies to the west of Louisville. This anticline has a closure of at least 30 feet, and covers an area of more than a township. It trends east-west in general but the western part also trends north-south. The northern flank of the anticline is well defined by outcrops along Crooked Creek and its tributaries whereas the south flank is defined only by a single test boring about six miles south of Crooked Creek (datum point 39). This portion of the Louisville anticline could be outlined by a number of shallow test borings

TABLE 2.—DATA TO ACCOMPANY STRUCTURE CONTOUR MAP (FIG. 4)

Location County, T. and R., and section	Map No.	Surface elevation	Estimated interval to key horizon	Elevation horizon	Stratum exposed or name of well
Clay					
T. 5 N., R. 5 E.					
25	1	467	0	467	Omega limestone
T. 4 N., R. 5 E.					
3	2	495	—25	470	Calcareous sandstone
4	3	502	—25	477	Platy limestone................
4	4	514	—25	489	Platy limestone
5	5	539	—40	499	Slaty shale
6	6	530	—25	505	Platy limestone
6	7	533	—25	508	Platy limestone
7	8	560	—40	520	Slaty shale
9	9	496	—25	471	Calcareous sandstone
9	10	506	—40	466	Slaty shale
9	11	523	—40	483	Slaty shale
10	12	486	0	486	Omega limestone
10	13	478	0	478	Omega limestone
10	14	499	—25	474	Calcareous sandstone
11	15	483	0	483	Omega limestone
12	16	485	0	485	Omega limestone
12	17	488	0	488	Omega limestone
12	18	488	0	488	Omega limestone
12	19	466	0	466	Omega limestone
13	20	494	—30	464	Slaty shale
13	21	511	—30	481	Slaty shale
13	22	510	—20	490	Fresh-water limestone
13	23	490	0	490	Omega limestone
13	24	489	0	489	Omega limestone
13	25	499	—30	469	Slaty shale
14	26	513	—30	483	Slaty shale
14	27	483	0	483	Omega limestone
14	28	525	—35	490	Slaty shale
20	29	508	—40	468	Slaty shale
27	30	534	—50	484	Harrell well
32	31	500	—40	460	Slaty shale
T. 4 N., R. 6 E.					
7	32	462	0	462	Omega limestone
17	33	469	—40	429	Slaty shale
17	34	461	—40	421	Slaty shale
19	35	485	?	485—	Shale above Omega limestone
20	36	467	0	467	Omega limestone
20	37	461	0	461	Omega limestone
23	38	439	—25	414	Calcareous sandstone
T. 3 N., R. 5 E.					
12	39	514	—73 (*a*)	441	Coal test near Dayton school
14	40	506	—25	481	Calcareous sandstone
15	41	541	—84 ?	457	Anderson well
23	42	544	—57	487	Old coal outcrop (*b*)
29	43	510	—57	453	Limestone above slaty shale
32	44	530	—57	473	Slaty shale

Table 2.—Concluded.

Location County, T. and R., and section	Map No.	Surface elevation	Estimated interval to key horizon	Elevation of key horizon	Stratum exposed or name of well
Marion					
T. 4 N., R. 4 E.					
19	45	561	—46	515	Underclay
26	46	544	—40	504	Limestone, slaty shale
26	47	541	—40	501	Limestone, slaty shale
32	48	521	0 ?	521	Coal, Omega ? horizon
T. 4 N., R. 3 E.					
23	49	602	—142	460	Kinmundy shaft
29	50	553	—66	487	Slaty shale, coal
31	51	557	—66	491	Slaty shale, coal
31	52	560	—70	490	Limestone
T. 4 N., R. 2 E.					
26	53	511	—66	445	Coal
T. 3 N., R. 3 E.					
10	54	560	—66	494	Coal
10	55	560	—66	494	Coal
13	56	533	22	555	Ferruginous limestone
24	57	528	22	550	Ferruginous limestone
24	58	524	0	524	Omega limestone (*c*)
26	59	519	22	541	Ferruginous limestone
T. 3 N., R. 4 E.					
1	60	506	—40	466	Slaty shale
4	61	502	0 ?	502	Omega limestone ?
4	62	504	0	504	Omega limestone
5	63	546	0	546	Omega limestone
5	64	508	35	543	Ferruginous limestone
5	65	504	35	539	Ferruginous limestone
6	66	557	0 ?	557	Black shale, Omega ? horizon
9	67	527	0	527	Omega limestone
9	68	536	0	536	Omega limestone
18	69	535	22	557	Ferruginous limestone
18	70	527	22	549	Ferruginous limestone
18	71	536	22	558	Ferruginous limestone
19	72	494	0	494	Omega limestone
30	73	512	0	512	Omega limestone
30	74	512	0	512	Omega limestone

(*a*) Reported by the driller; depth to black slaty shale 16 feet; complete log not available.

(*b*) Geological Survey of Illinois, Vol. XI, p. 92, 1875. No outcrop now visible; elevation taken on flat swampy area.

(*c*) Interval to ferruginous limestone 22 feet.

and such test drilling seems desirable before choosing a location for a deep test.

Omega Anticline.—An anticline covering an area of about one township and trending north-northeast south-southwest is located in the west part of the area mapped. Its axis extends from a point about 3 miles east of Kinmundy southward, with a slight bend to the west, to the southern part of sec. 26, T. 3 N., R. 3 E. The anticline is named for the village of Omega located on its eastern flank. The eastern flank is well defined by two groups of outcrops, one north and northeast of Omega on Lost Fork and its tributaries, the other southwest of Omega on Bee Branch and tributaries. The western flank is poorly defined as there are no outcrops except in a small area on Dums Creek near Brubaker in sec. 10, T. 3 N., R. 3 E. The log of the Kinmundy shaft (Appendix log No. 6) shows 10 feet of black shale at a depth of 76 feet which is correlated as the black slaty shale which occurs widespread in the Crooked Creek area. Below the top of the black "slate" 66 feet (depth 142 feet), is a "limestone conglomerate," 1 foot thick which is correlated as the Omega limestone. This interval compares with that of 57 feet found 15 miles east-southeast in sec. 12, T. 3 N., R. 5 E. (datum point 39, Fig. 4). If this interpretation of the Kinmundy shaft log is correct there is a northwest dip from the crest of the Omega anticline of nearly 100 feet The scattered outcrops of black slate and coal west and south of Kinmundy are tentatively considered to be the same horizon. There is considerable uncertainty about the correlation of the coal at Brubaker and accordingly about the west dip shown for the Omega anticline. Structure test drilling should be done to determine whether or not such a dip actually exists before locating a deep test for oil and gas.

Xenia and Iola Domes.—Evidence was found for two minor closed domes, one to the north of Xenia centering about sec. 23, T. 3 N., R. 5 E., the other southwest of Iola centering in the nothern part of sec. 7, T. 4 N., R. 5 E. Both of these domes appear to be connected with the Omega anticline, the Xenia dome by an axis trending a little north of west and south of east, the Iola dome by an axis trending northeast-southwest.

OIL AND GAS PROSPECTS

In order for a structure, as mapped on surface beds, to form a trap effective in the accumulation of oil and gas it must extend downward beneath the surface to the horizon of reservoir beds. It is therefore pertinent to inquire whether or not the anticlines and domes mapped in figure 4 probably extend sufficiently deep into the subsurface strata. Because few subsurface data are available this question cannot be answered definitely. The best that can be done pending further drilling is to compare these structures as to form and size with other structures in the region which are known to extend into the subsurface.

The Sandoval dome[1] about 10 miles west of the west edge of the territory mapped in figure 4 has been mapped on Herrin (No. 6) coal and on the top of the Benoist sand, about 950 feet stratigraphically lower. Although the pre-Pennsylvanian unconformity intervenes between these two horizons their structure is quite similar, the dips being steeper on the lower horizon. The

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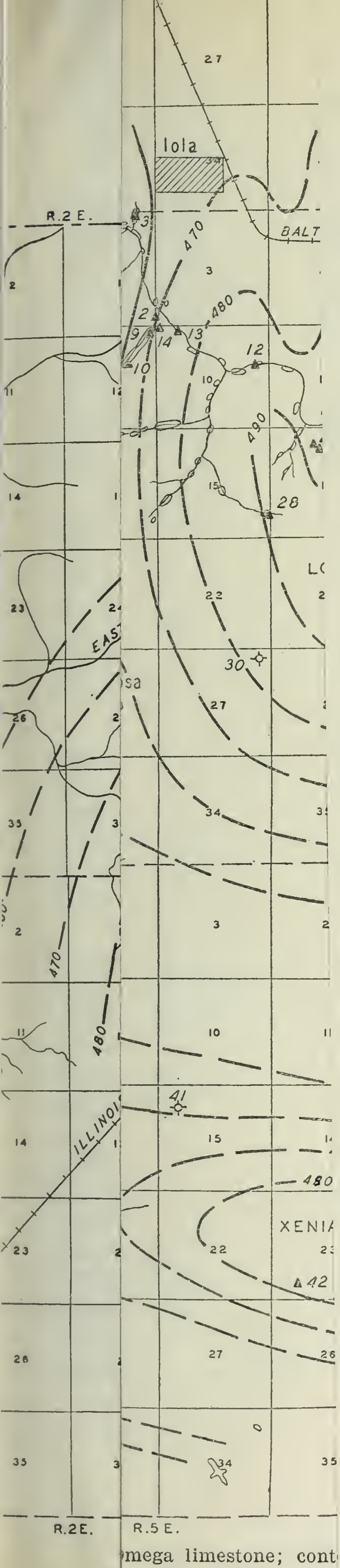
[1] Bell, A. H., Structure of Centralia and Sandoval oil fields: Illinois State Geol. Survey Illinois Petroleum No. 10, p. 9, 1927.



mega limestone; cont

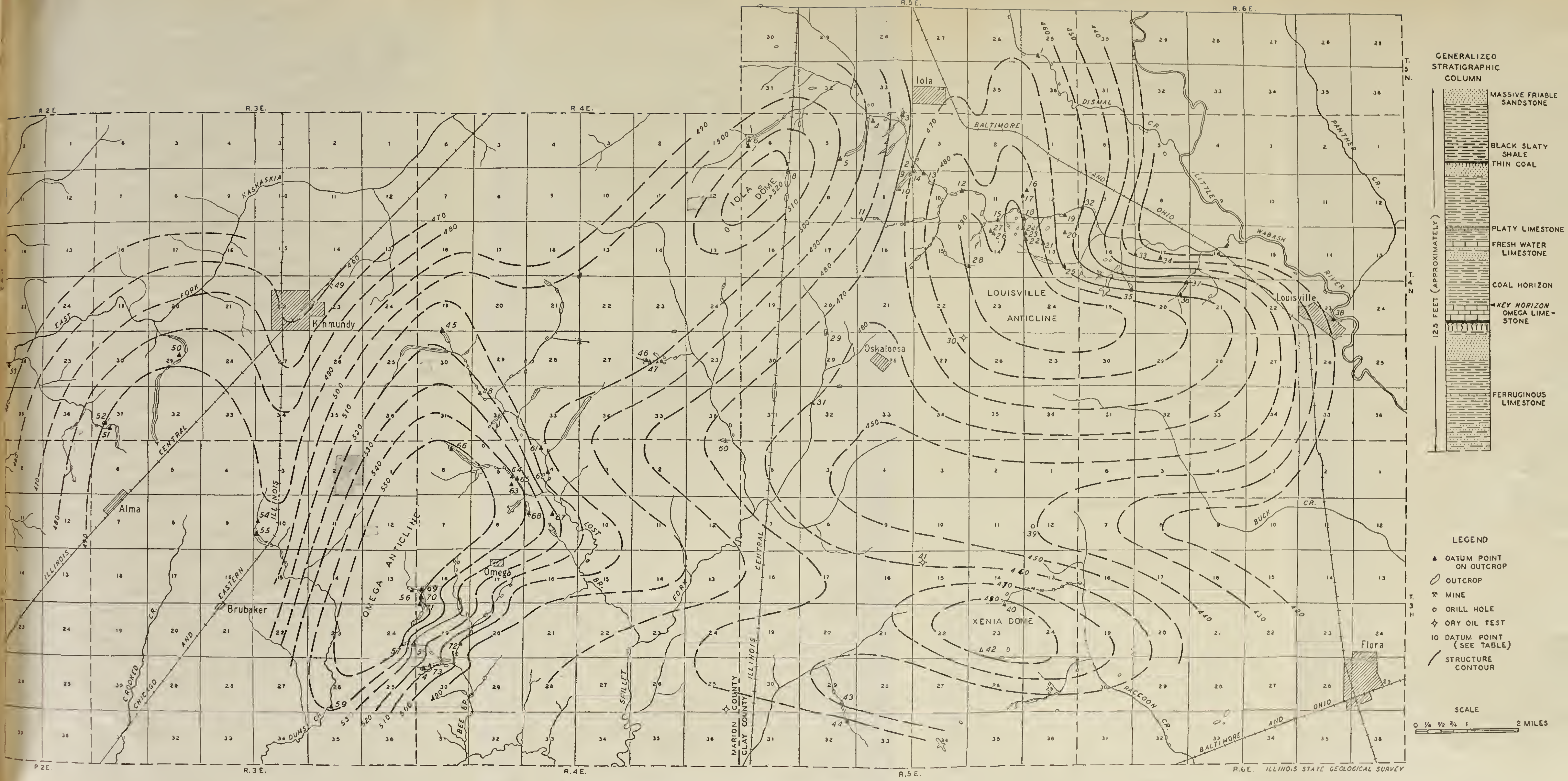


Fig. 4.—Structure contour map of parts of Clay and Marion counties, Illinois. Key horizon, top of Omega limestone; contour interval 10 feet; datum sea-level.

closure on No. 6 coal amounts to about 60 feet as compared with 30 feet or more on the Omega limestone for the Louisville anticline. Both structures trend approximately east and west. The steeper dips on the north flank of the Louisville anticline shown in figure 4 are about 50 feet per mile on the Omega limestone (although some local dips here are much steeper) as compared with a maximum of about 90 feet per mile for the Sandoval dome. It should be remembered, however, that the horizon of coal No. 6 is about 700 feet lower stratigraphically than the Omega limestone and that it is possible that on the Louisville anticline dips at the horizon of coal No. 6 are steeper than those of the beds exposed at the surface.

The maximum dips of the surface beds on the east flank of the Omega anticline as shown in figure 4 are about 70 or 80 feet per mile. (Here again some local dips are much steeper.) The trend of the axis of the Omega anticline is nearly parallel to that of the Centralia and DuQuoin monoclines (see figs. 2 and 3) which are pronounced structural features and which doubtless extend to great depth. From a consideration of these facts it appears probable that the Louisville and Omega anticlines extend downward into the pre-Pennsylvanian strata.

Development.—Few test wells for oil and gas have been drilled on or near the Louisville anticline, the only one of which a record is available being the J. H. Harrell well, sec. 27, T. 4 N., R. 5 E., Clay County, total depth 2,302 feet (datum point No. 30, Fig. 4, No. 2, Fig. 2). This well had a show of heavy oil from 2,140-2,152 feet in a sandstone tentatively correlated as Tar Springs. No deep well has been drilled on the Omega anticline. The log of the Harrell well is given in the Appendix, log No. 1.

Possible Oil Producing Horizons.—Within the area mapped in figure 4, structure contour map on Omega limestone, only three wells have been drilled below the base of the Pennsylvania system. One of these had a show of oil in a sandstone in the middle part of the Chester series, tentatively classified as the Tar Springs formation. No wells have yet reached the lower part of the Chester series in which occur the Stein and Benoist sands of the Sandoval field, the Carlyle sand of the Carlyle field, and the Kirkwood sand of the Lawrence County field, where these Lower Chester sandstones have been prolific producers. In the Lawrence County field, large yields of oil have also been obtained in somewhat more restricted areas from the McClosky "sand" in the Ste. Genevieve oolitic limestone of the Middle Mississippian series. All of these horizons as well as the Devonian-Silurian limestone ("Niagaran") and Kimmswick ("Trenton") limestone have possibilities of oil or gas production on the structures described herein.

Table 3 gives estimated depths to possible producing horizons for a location approximately on the Louisville anticline.

Table 3.—Estimated Depths to Pre-Pennsylvanian Horizons

Horizon	Estimated depth at location of Harrell well (datum point 30) Sec. 27, T. 4 N., R. 5 E.	Remarks
Cypress formation..........	2480	Kirkwood sand, productive in Lawrence County Stein sand, formerly productive in Sandoval field, Marion County Carlyle sand productive in Carlyle field, Clinton County
Yankeetown (?)............	2600	Benoist sand productive in Sandoval field, Marion County Tracy sand, productive in Lawrence County
Base Chester top Ste. Genevieve...............	2700	McClosky sand, porous zone in upper 80 feet of Ste. Genevieve oolitic limestone, productive in Lawrence County field.
Top Devonian-Silurian limestone ("Niagaran").......	4150	Productive in Martinsville field, Clark County and Siosi field, Vigo County, Indiana
Top Kimmswick-Plattin ("Trenton").............	5550	Productive in Dupo field, St. Clair County, and Westfield and Martinsville pools, Clark County
St. Peter sandstone.........	6350	No oil or gas production in Illinois or adjacent states. Approximately correlated with "Wilcox" sand of Oklahoma and Kansas

The St. Peter sandstone lies below the so-called "Trenton" which includes the Kimmswick, Plattin, and Joachim formations of southwestern Illinois and southeastern Missouri. Its approximate correlation with the "Wilcox" sand of Oklahoma and Kansas have led many to believe that it has favorable prospects of oil production in Illinois and other states east of Mississippi River. No shows of oil, however, have been reported thus far from the St. Peter in Illinois. In the northern part of Illinois this formation contains fresh water. At the two places in the Southeastern Illinois field where it has been drilled the St. Peter contained salt water, in Clark County about 45,000 parts per million of dissolved solids, in Lawrence County about 175,000 p.p.m. Both of these tests were located in areas of oil production from higher horizons. Aside from the foregoing, there is little on which to base an opinion as to the oil prospects of the St. Peter in the Illinois basin area.

The Iola and Xenia domes appear to be structures of considerably smaller closure and areal extent than the Louisville and Omega anticlines. However, it is believed that they deserve consideration in a program for testing the area discussed, particularly if either the Louisville or Omega anticline should prove productive.

Recommendations.—Because of their location in the Illinois basin area, and the presence of several possible producing formations which produce oil to the east and to the west, it is believed that the Louisville and Omega anticlines have possibilities for oil or gas production. However, since the available data are far from complete, it is not possible at present to choose any one location which deserves testing in preference to many other possible locations on these structures. In view of this situation it is believed that the wisest procedure would be either to make a number of shallow tests to some recognizable key bed, in order to outline the structure in greater detail than is now possible, and to discover any structural closures that may be present[2] or to use some geophysical method, as for example the seismograph, in order to supplement geologic studies. Test borings for structure could be made either by a small churn drill or a diamond drill. In either case the samples or cores should be studied by a geologist. The State Geological Survey is ready to cooperate with anyone who drills either structure tests or oil tests, by making a geologic study of sample cuttings and driller's logs, by correlating the new data with that already in hand, and by making whatever recommendations can be made for further testing.

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[2] The advantages of structure test drilling in Illinois are discussed in Moulton, G. F., "Proper Testing for Oil Structures in Illinois and Some Areas Deserving Such Testing"; Illinois State Geological Survey Report of Investigations No. 6.

CHAPTER IV

DESCRIPTION OF OUTCROPPING BEDS

J. Marvin Weller

KEY BEDS

The glacial drift is comparatively thin throughout much of northwestern Clay and northeastern Marion counties and small outcrops are abundant in certain well dissected areas, particularly upon the south side of Crooked Creek in Clay County and along Lost Fork and Bee Branch and their tributaries in Marion County. The outcropping strata constitute a section over 100 feet thick consisting mainly of shale but with thinner beds of limestone, sandstone, clay, and coal. This section varies greatly in lithological character from place to place, and most of its members may change abruptly in thickness or disappear within short distances. Two of the beds, however, are quite persistent and constant in lithology. These are the Omega limestone in the lower part and the thick black slaty shale in the upper part of the section. They are the two principal key horizons upon which the accompanying structural contour map (Fig. 4) is based. Besides these beds two others have been utilized for structural control where elevations cannot be obtained upon either of the more persistent beds. These subordinate key beds are the ferruginous limestone below the Omega limestone and the fresh-water and platy limestones which occur between the Omega limestone and the black slaty shale.

STRATIGRAPHIC INTERVALS

Because most of the rock outcrops are confined to the beds and immediate banks of the streams, there are comparatively few localities where the intervals between the key horizons can be accurately determined. The only place where the Omega limestone and black slaty shale outcrop in close proximity is in the NE. ¼ of the NW. ¼ sec. 14, T. 4 N., R. 5 E. (map Nos. 26, 27, Fig. 4). There the top of the shale lies 30 feet above the top of the limestone. These same two beds, however, have both been penetrated in the shaft of the old Kinmundy coal mine (map No. 49, Fig. 4), located just northeast of town, and in the Dayton School well, in the NW. ¼ of the SW. ¼ sec. 12, T. 3 N., R. 5 E. (map No. 39, Fig. 4). At these places this interval is 66 and 57 feet respectively.

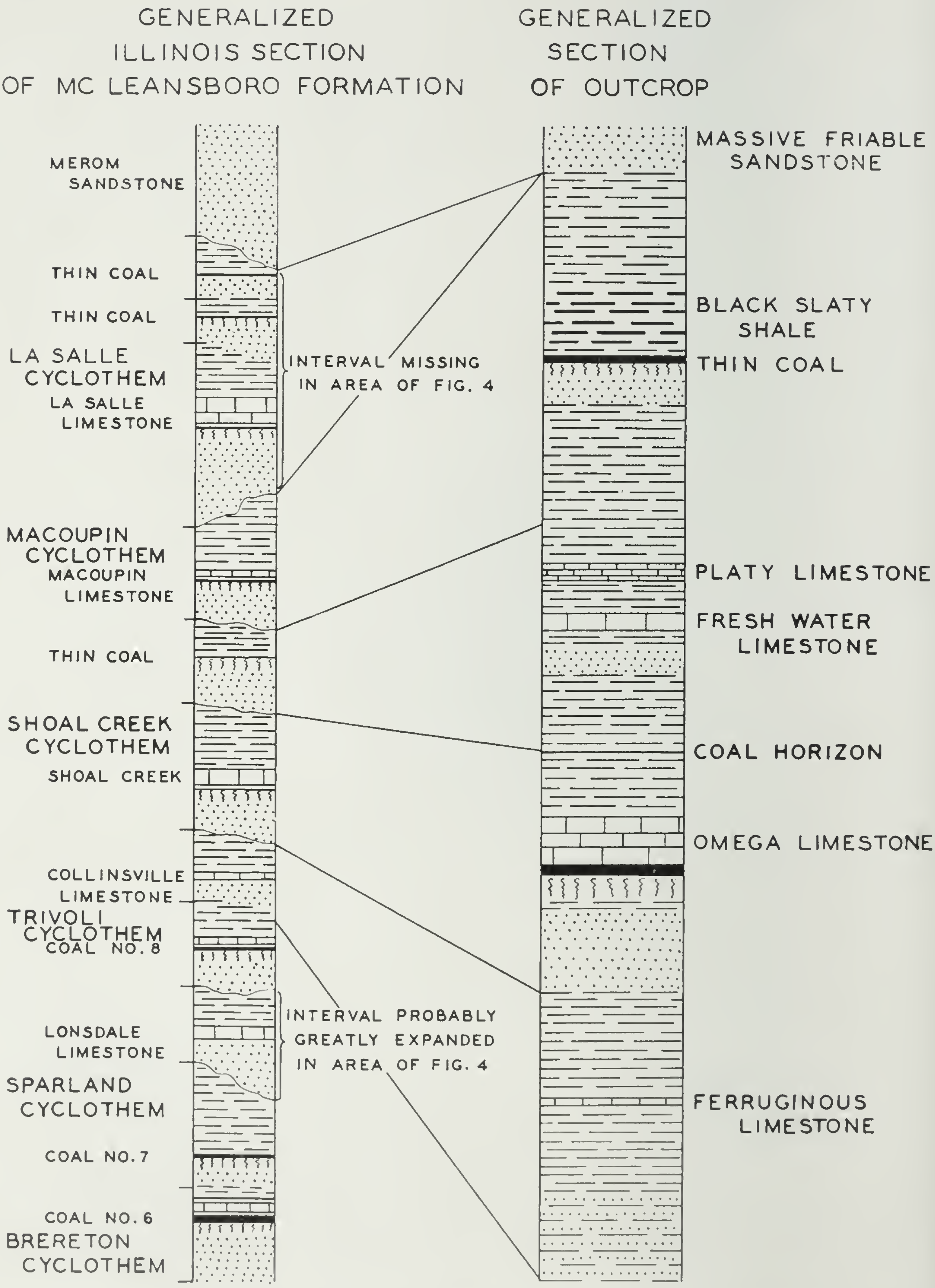

Fig. 5.—Correlation of outcropping beds with the general stratigraphic section of the McLeansboro strata in Illinois.

Near the center of the east line of the SE. 1/4 sec. 24, T. 3 N., R. 3 E. (map No. 58, Fig. 43, the top of the ferruginous limestone lies 22 feet below the top of the Omega limestone. In the center of the SE. 1/4 of sec. 5, T. 3 N., R. 4 E. (map Nos. 63 and 64, Fig. 4), the difference in elevation of these horizons is 38 feet but because of the probable dip of the strata between the two outcrops the actual interval is believed to be somewhat less.

The top of the fresh-water limestone occurs 25 feet above the top of the Omega limestone near the west line of the NW. 1/4 sec. 13, T. 4 N., R. 5 E. (map Nos. 22 and 23, Fig. 4), and an approximately similar interval separates the Omega from the top of the platy limestone in the NW. corner of sec. 10 and adjacent part of sec. 9 (map Nos. 9 and 13, Fig. 4) of the same township.

The top of the platy limestone lies 14 feet below the top of the black slaty shale near the center of the S. 1/2 sec. 13, T. 4 N., R. 5 E., but in the NE. 1/4 sec. 9 (map Nos. 9 and 10, Fig. 4) of the same township, this interval has increased to about 30 feet.

BEDS BELOW OMEGA LIMESTONE

Beds below the Omega limestone are exposed in Clay County principally along Crooked Creek in secs. 10, 11, and 12, T. 4 N., R. 5 E. Throughout these sections the limestone is generally immediately underlain by a coal bed which attains a maximum thickness of nearly one foot but appears to be locally absent as in the SE. 1/4, SW. 1/4 sec. 11 (map No. 15, Fig. 4) and the SW. 1/4, SW. 1/4 sec. 12 (map No. 18, Fig. 4). Underclay below the coal is comparatively thin and poorly developed and grades downward into irregularly laminated greenish-gray shale. This in turn grades downward into sandy beds which attain a maximum observed thickness of about 15 feet. They may consist of very sandy shale or shaly to thin-bedded fine-grained micaceous sandstone. In the SE. 1/4 SE. 1/4 sec. 11, several feet of gray silty shale with large oval ironstone concretions outcrops beneath the level of the sandstone. These are the oldest beds exposed in Clay County. A similar section consisting of coal, underclay, thin-bedded sandstone and gray shale underlies the Omega limestone in Marion County in the NW. 1/4 sec. 9, T. 3 N., R. 4 E. (near map No. 68, Fig. 4). Sandstone apparently belonging below the Omega limestone is well exposed and rises nearly to prairie level in the NE. 1/4 of the adjoining sec. 8.

Southwest of Omega in Marion County the strata below the Omega limestone are exposed along the west fork of Bee Branch in secs. 13 and 24, T. 3 N., R. 3 E., and secs. 18 and 19, T. 3 N., R. 4 E. Here the coal is very thin or absent and the Omega limestone closely overlies a medium light gray, soft underclay. The ferruginous limestone is well exposed in the SW. 1/4 sec. 18 (map No. 69, Fig. 4), where it is very fossiliferous (Fig. 6). The strata between this member and the Omega limestone, however, are not completely exposed in this vicinity. The lack of outcrops of this part of the section suggests that it consists mainly of shale. The ferruginous limestone may occur below drainage along Crooked Creek and is probably present below the strata mentioned as occurring in the NW. ¼ sec. 9, one mile northeast of Omega. Evidence indicates that the interval between the Omega and ferruginous limestones increases in those areas where sandstone forms an important part of the intervening strata.

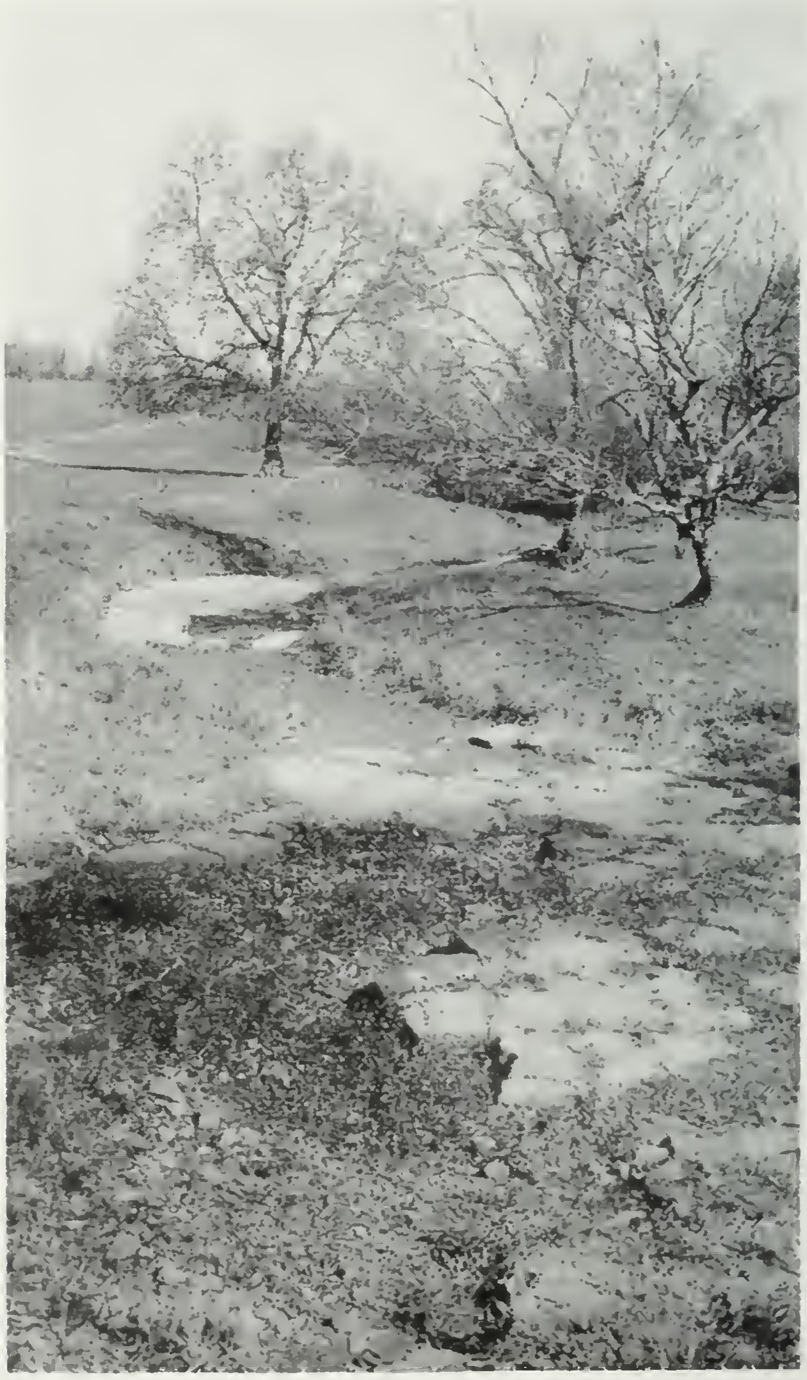

Fig. 6.—Ferruginous limestone in the bed of the west fork of Bee Branch, NW. ¼ SW. ¼ sec. 18, T. 3 N., R. 4 E. (map No. 69, Fig. 4).

Where best developed along the west fork of Bee Branch, the ferruginous limestone consists of less than one foot of dark gray, very impure, fine-grained limestone which weathers to a deep brownish-red color. It is locally very fossiliferous and contains numerous large pelecypods and gastropods. The isolated outcrop on Dums Branch in the SW. ¼ sec. 26, T. 3 N., R. 3 E. (map No. 59, Fig. 4), resembles this bed as exposed on Bee Branch but is somewhat more impure. In the NW. ¼ SE. ¼ sec. 9, T. 3 N., R. 4 E., the ferruginous limestone is only 2 to 4 inches thick, very conglomeratic and only sparingly fossiliferous, and it shows a similar development at several outcrops (map Nos. 64 and 65, Fig. 4) on the southwest side of the creek which flows through sec. 5 of this same township. The ferruginous limestone is correlated with the Collinsville limestone of the Illinois general stratigraphic section (Fig. 5).

On the west fork of Bee Branch the ferruginous limestone is underlain by 10 feet or more of gray silty shale, the lower part of which contains *Estheria*. Below this occurs a questionable, poorly developed underclay and very sandy, gray to brownish shale, with impure flattened ironstone concretions.

In the SE. ¼ sec. 5, T. 3 N., R. 4 E. (map No. 64, Fig. 4), the ferruginous limestone is underlain by about a foot of sandy shale, below which occurs a small thickness of thin-bedded, fine-grained, more or less calcarous sandstone. Up-stream to the west the ferruginous limestone rises in the banks which are composed of greenish-gray to gray sandy shale and it may be traced nearly to the road lying near the west line of this section. West of this road and mainly in sec. 6 are more or less continuous outcrops of sandy shale and shaly sandstone which continue upward nearly to the level of the prairie. Near the upper part of this sequence in NW. ¼ NE. ¼ sec. 6 (map No. 66, Fig. 4) occurs a poor exposure of coaly shale with associated calcareous siltstone containing *Spirorbis* and wide flattened stem impressions which somewhat resembles the platy limestone described below, although it does not exhibit the characteristic platy structure of this latter bed.

The relations of the beds exposed in sec. 6 to those observed in sec. 5 are uncertain. The lower part of this stratigraphic section seems to occur definitely below the ferruginous limestone but this stratum has not been recognized higher in the section and the coaly shale is unlike any bed known in this area below the Omega limestone. There is a possibility that the Omega and ferruginous limestones have been cut out along an unconformity and that the coaly shale represents a horizon younger than the Omega limestone. Evidence bearing on the existence of such an unconformity is presented below.

OMEGA LIMESTONE

The Omega limestone is a light gray, hard, dense, generally fine-grained, pure limestone, which is commonly 4 to 9 feet thick. It outcrops along Crooked Creek from the NW. corner of sec. 10, T. 4 N., R. 5 E. (map No. 13, Fig. 4) to the SW. ¼ sec. 7, T. 4 N., R. 6 E. (map No. 32, Fig. 4), attaining a thickness of 4 to 5 feet except locally where it may disappear entirely as in part of the SW. ¼ SW. ¼ sec. 12, T. 4 N., R. 5 E., or thicken to as much as 13 feet as in the SW. ¼ SE. ¼ sec. 11 (map No. 15, Fig. 4) of the same township where it becomes quite silty and contains fairly abundant, well preserved fossils. On Dismal Creek in the SW. ¼ sec. 25, T. 5 N., R. 5 E. (map No. 1, Fig. 4), this bed attains a thickness of nearly 10 feet of light gray, fairly pure, quite fossiliferous limestone. In the NW. ¼ sec. 9, T. 3 N., R. 4 E. (map No. 68, Fig. 4) (Marion County), it is 5 to 6 feet thick. The main upper part is hard, gray, massive limestone but the basal bed, less than one foot thick, is dull bluish-gray and impure and contains many small fossil fragments, mainly crinoid stems, which gives it a granular and crystalline structure. In the NW. ¼ sec. 30 (map Nos. 73 and 74, Fig. 4) of the same township where it has been extensively quarried for local uses, the Omega consists of 6 to 7 feet of light gray, hard, massive limestone, the upper part of which contains abundant fusulinids (Fig. 7).

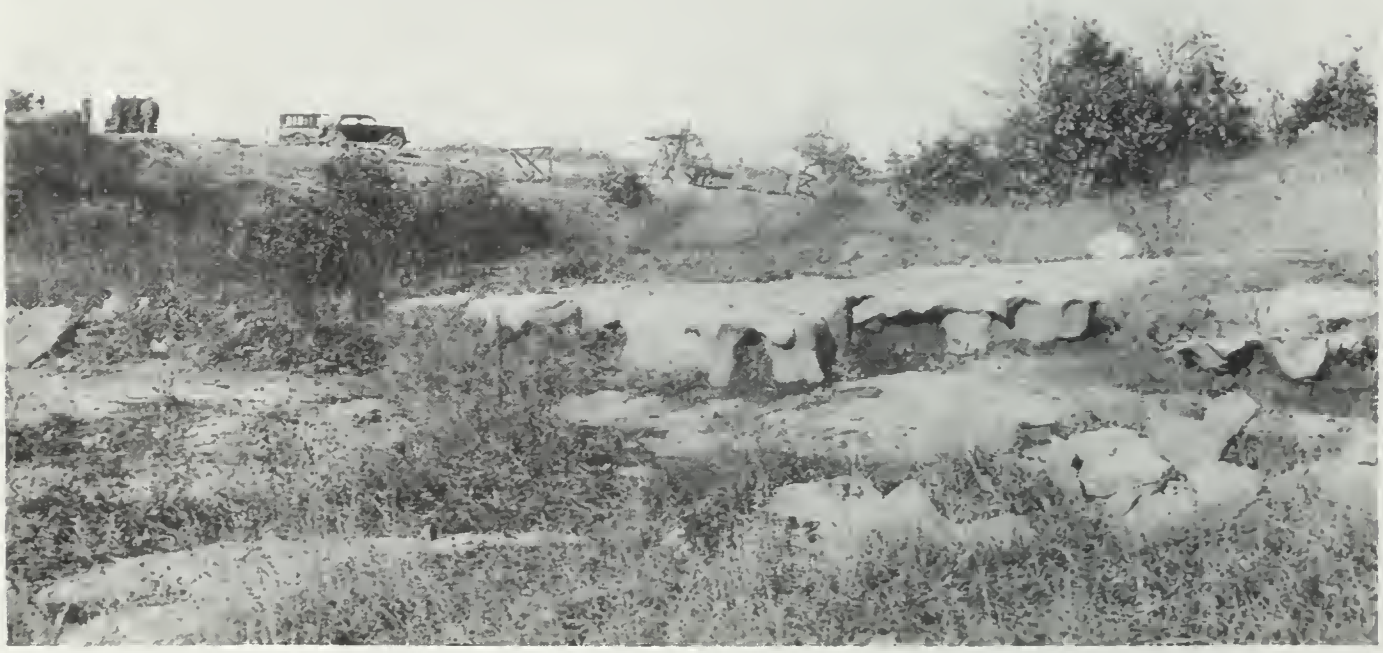

Fig. 7.—Solution-pitted upper surface of the Omega limestone above the quarry in the NE. ¼ NW. ¼ sec. 30, T. 3 N., R. 4 E. (near map No. 73, Fig. 4).

Limestone conglomerate which may contain marine fossils is closely associated with the Omega limestone near the NW. corner sec. 13, T. 4 N., R. 5 E. (map No. 23, Fig. 4) and in the SW. ¼ sec. 19, T. 3 N., R. 4 E. (map No. 58, Fig. 4). The conglomerate consists mainly of gray limestone pebbles up to 3 or 4 inches in diameter, although most of them are much smaller. The pebbles appear to have been derived from the Omega limestone and some of them are brownish on the outside as though they had been weathered before reconsolidation. The matrix of the conglomerate is also limestone but appears to be less pure than the pebbles and may be quite sandy. It is developed to a maximum observed thickness of about 10 feet. At the first locality mentioned above both conglomerate and Omega limestone occur at the same elevation separated by only 6 feet of covered slope. At the second locality conglomerate overlies Omega limestone in the road south of the creek. On the north side of the creek and also in the road only conglomerate is present at about the same elevation, and down stream to the east, conglomerate occurs at lower levels. It is believed that this conglomerate marks an unconformity and is much younger than the Omega limestone which it appears to cut out locally. Similar material has been observed much higher than the Omega limestone and is described in a later paragraph.

The outcrops of Omega limestone that extend eastward along the hillsides from the quarries in the NW. 1/4 sec. 30, T. 3 N., R. 4 E. (map Nos. 73 and 74, Fig. 4), end abruptly in the NW. 1/4 NE. 1/4 of this section, and a short distance farther massive sandstone occurs on the hill slopes at about the same level. Likewise the outcrops of Omega limestone which occur along the east fork of Bee Branch in the SE. 1/4 of sec. 19 of the same township, cease abruptly near the south line of this section and no outcrops of the Omega limestone are known to occur farther south or east in Marion County. It is believed that the Omega limestone has been cut out here by an unconformity.

In the NW. 1/4 sec. 9 and the S. 1/2 sec. 4, T. 3 N., R. 4 E., the Omega limestone is dipping to the northeast. In the NW. 1/4 sec. 4, (map No. 61, Fig. 4) an outcrop of limestone irregularly overlain by massive sandstone is present just above water level in the east bank of Lost Fork. This limestone occurs at about the proper elevation if the dip previously mentioned continues this far north. The limestone, however, although massive, does not otherwise resemble the Omega; it is much more impure, contains very abundant small crinoid stem segments as well as some larger fossils, and its brownish-gray color is altered to deep brownish-red by weathering. If this is the Omega limestone, the outcrops occurring farther up Lost Fork must overlie this latter member. If it is not the Omega limestone, which appears possible, it may be the ferruginous limestone, although it resembles this only in its weathered color. In the latter case the massive sandstone occurring in this vicinity overlies an unconformity that has cut out the Omega limestone and the outcrops in the SW. 1/4 sec. 29, SE. 1/4 sec. 30 and NW. 1/4 sec. 32, T. 4 N., R. 4 E., which resemble no others observed in this vicinity, probably belong beneath the ferruginous limestone and would therefore be the oldest beds exposed within this area, perhaps extending down to coal No. 8 of the Illinois general stratigraphic section. The occurrence of an *Estheria*-bearing horizon seen near the NW. and SE. corners of sec. 32, the center of the N. 1/2 sec. 28 and the center of the E. 1/2 sec. 21, somewhat similar to that occurring beneath the ferruginous limestone on the west fork of Bee Branch, suggest that this interpretation may be correct. However, in the interpretation of structure given in figure 4, the outcropping strata in secs. 28, 29, 30, and 31, T. 4 N., R. 4 E., are all assumed to be above the Omega.

Abundant large blocks of Omega limestone occur in the glacial drift in the breaks of the prairie east and southeast of Kinmundy and are evidence that this bed is present immediately below the drift not far to the north. No actual exposures of the Omega are known in Marion County, however, north of T. 3 N., R. 4 E.

The Omega limestone is believed to be equivalent to the Shoal Creek limestone of the Illinois general stratigraphic section (Fig. 5).

BEDS OVERLYING OMEGA LIMESTONE

Although beds younger than the Omega limestone occur in northeastern Marion County, the sequence is known only from the exposures in the vicinity of Crooked Creek in northwestern Clay County. In the south bank of Dismal Creek in the SE. 1/4 NW. 1/4 sec. 5, T. 4 N., R. 6 E., a coal horizon consisting of 1/4 inch of smutty material and overlying a poorly developed underclay about 6 inches thick occurs about 10 or more feet above the Omega limestone, from which it is separated by finely sandy shale with impure ironstone concretions (Fig. 5). Blocks of massive, fine-grained, hard sandstone 4 feet thick have tumbled down the slope from a position 6 feet or more above the coal horizon. In the NE. 1/4 sec. 20 of the same township 15 feet of gray shale, sandy above and silty below, with large ironstone concretions overlies the Omega limestone and similar shale occurs in the NE. 1/4 of the adjoining sec. 19 (map No. 35, Fig. 4), although the limestone is not exposed.

Sandstone probably equivalent to that mentioned above outcrops at several places on the south side of Crooked Creek and the southwest side of Little Wabash River between the Baltimore and Ohio Railroad and Louisville in secs. 14, 15, 16, and 23, T. 4 N., R. 6 E. It varies from 2 to 4 feet in thickness and is massive, fine-grained, hard, and very calcareous. At the mouth of Crooked Creek, a thin smutty coal horizon, probably identical with that observed on Dismal Creek in sec. 5, occurs in a silty to sandy shale succession 10 feet below this bed. Shale and underclay, in part mottled reddish, overlie the calcareous sandstone in secs. 15 and 16.

The same calcareous sandstone outcrops in the bed of a small ravine at the road crossing in the N. center of sec. 19, T. 4 N., R. 6 E., and descends to the north at a rate about equal to the gradient of the hollow. In the road a locally developed coal horizon above 4 feet of mottled reddish underclay occurs some 6 feet above the sandstone. The coal horizon is succeeded above by drab to gray or brownish-gray silty shale containing an irregular discontinuous limestone bed in its lower part. This limestone is hard, crystalline, brownish-gray to medium dark gray, somewhat impure and ferruginous and contains marine fossils. Near the center of the W. ½ SE. ¼ sec. 18 to the north this limestone has been observed about 20 feet below the black slaty shale described below. It is possible that the 6-inch coal exposed in the west bank of the Little Wabash River south of the bridge at Louisville is equivalent to the coal horizon mentioned above.

A composite stratigraphic section built up from the outcrops described above indicates that the interval between the top of the black slaty shale and the top of the Omega limestone is about 55 feet in this vicinity.

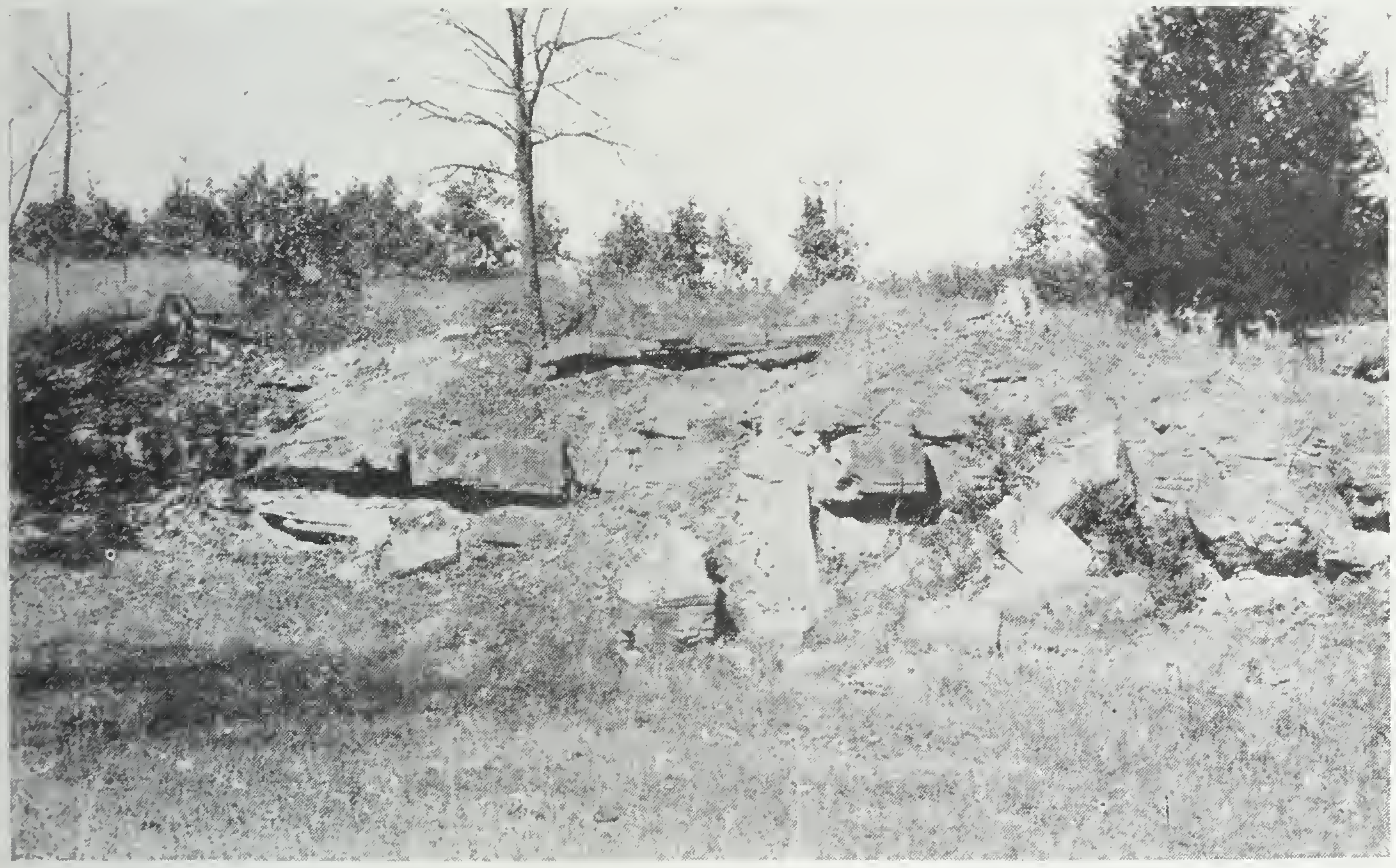

Fig. 8.—Calcareous sandstone that lies between the platy fresh-water and Omega limestones, NW. corner sec. 10, T. 4 N., R. 5 E. The thicker sandstone ledge in the middle grades locally into impure limestone with *Spirorbis* and small thin shelled non-marine pelecypods (near map No. 9, Fig. 4).

Because the fresh-water and platy limestones are absent from the section described above, it is difficult if not impossible to correlate these beds with those which occur to the west. Near the NW. corner of sec. 10, T. 4 N., R. 5 E. (map No. 9, Fig. 4), a calcareous sandstone occurs at about this same position in the sequence. This bed is described later in connection with its possible equivalence to the fresh-water limestone.

A thin coal horizon is exposed in the NE. ¼ NW. ¼ sec. 4, T. 4 N., R. 5 E., some distance below the fresh-water limestone and may be the continuation of that occurring beneath the calcareous sandstone on Dismal Creek and at the mouth of Crooked Creek. A somewhat similar coal horizon is exposed at several places along the creek which flows east across the S. ½ sec. 13, T. 3 N., R. 5 E. It probably underlies platy limestone outcropping in the creek bed near the west line of this section. A fairly good coal horizon is present 5 feet or more below the fresh-water limestone in a tributary on the north side of Crooked Creek in the NE. ¼ sec. 4, T. 4 N., R. 5 W. (map No. 3, Fig. 4). A thin coal smut is also exposed in the road cut on the line between sections 22 and 23, T. 5 N., R. 5 E. just south of Dismal Creek (north of the edge of the area shown in Fig. 4) and may represent the same horizon but other outcrops which might substantiate this conclusion are lacking.

There are few, if any, exposures of the beds intervening between the platy and fresh-water limestones and the Omega limestone in sections 10, 11, 12, and 13, T. 4. N., R. 5 E., and it is probable, therefore, that this part of the stratigraphic section consists almost wholly of shale.

In sections 31 and 32, T. 5 N., R. 5 E., and sec. 6 to the south there are extensive exposures of more or less sandy shale and shaly to thin-bedded sandstone that underlie the platy limestone and it is probable that this part of the section has thickened considerably.

No strata equivalent to those described above have been definitely recognized in northeastern Marion County.

FRESH-WATER LIMESTONES

Fresh-water limestone occurring in the midst of the sequence between the Omega limestone below and the black slaty shale above outcrops at numerous places along the small tributaries of Crooked Creek in secs. 4, 6, 9, 13, 14, and 15, T. 4 N., R. 5 E., and in sec. 14, T. 3 N., R. 5 E. Similar rock is exposed a short distance west of the area shown in figure 4 in the south bank of the East Fork of Kaskaskia River in the SE. ¼ NE. ¼ sec. 6, T. 3 N., R. 2 E. The fresh-water limestone occurs in one to several, thin, more or less lenticular beds and varies greatly in lithology. The most persistent type is quite silty and impure and consists of thin and even laminae that weather to platy fragments. It attains a maximum thickness of about 15 inches and is of medium gray color where fresh but upon exposure bleaches nearly white. Marine fossils are absent from this bed although *Spirorbis*, ostracods, small thin shelled pelecypods and more or less carbonized plant stem impressions are more or less abundant locally. This platy limestone is the uppermost bed of the fresh-water sequence and may be observed in the center W. ½ sec. 6 (map Nos. 6 and 7, Fig. 4), NE. ¼ NW. ¼ sec. 4 (map No. 4, Fig. 4), NE. ¼ NE. ¼ sec. 9 (near map No. 9, Fig. 4), central part of sec. 15, NE. ¼ SW. ¼ sec. 13, all in T. 4 N., R. 5 E., and SW. ¼ sec. 13, T. 3 N., R. 5 E.

In the NE. ¼ sec. 4, T. 4 N., R. 5 E. (map No. 3, Fig. 4), the typical platy type of limestone is absent and the fresh-water limestone is light gray, lithographic in texture, and breaks with a conchoidal fracture. In the NE. ¼ SW. ¼ sec. 13 of the same township hard, dense, fine-grained, somewhat earthy fresh-water limestone that is medium light gray when fresh but weathers to yellowish-brown, appears to occur a short distance beneath a bed of the typical platy limestone (Fig. 9). Similar material without the overlying platy bed is exposed just north of the road near the northwest corner of this same section (map No. 22, Fig. 4) and also in another small ravine a short distance to the west. In the northeast corner of section 9 of the same township (map No. 9, Fig. 4) more or less calcareous sandstone in two beds separated by 2½ feet of clay or shale and attaining a total thickness of about 17 feet occurs three or four feet below platy fresh-water limestone. The shale or clay separating the two beds of sandstone contains many small calcareous nodules, particularly concentrated in the lower part where they attain maximum diameters of 3 to 4 inches. The upper part of the underlying sandstone is very calcareous, locally contains limestone nodules similar to those occurring in the softer beds above, and at a few places imperceptibly grades into what appears to be fairly pure limestone with *Spirorbis* and small thin shelled pelecypods. This association suggests that the calcareous sandstone may be equivalent to the yellowish-brown weathering limestone in sec. 13 described above. It is also possible that very calcareous sandstone without fossils or limestone nodules occurring one foot below platy limestone near the center W. ½ sec. 6 of the same township may be equivalent to this bed. If there actually is such a sandy calcareous member more or less persistent throughout this area, it is likewise possible that the calcareous sandstone previously described in sec. 19, T. 4 N., R. 6 E., and at various places on Crooked Creek and Little Wabash River as far southeast as Louis-

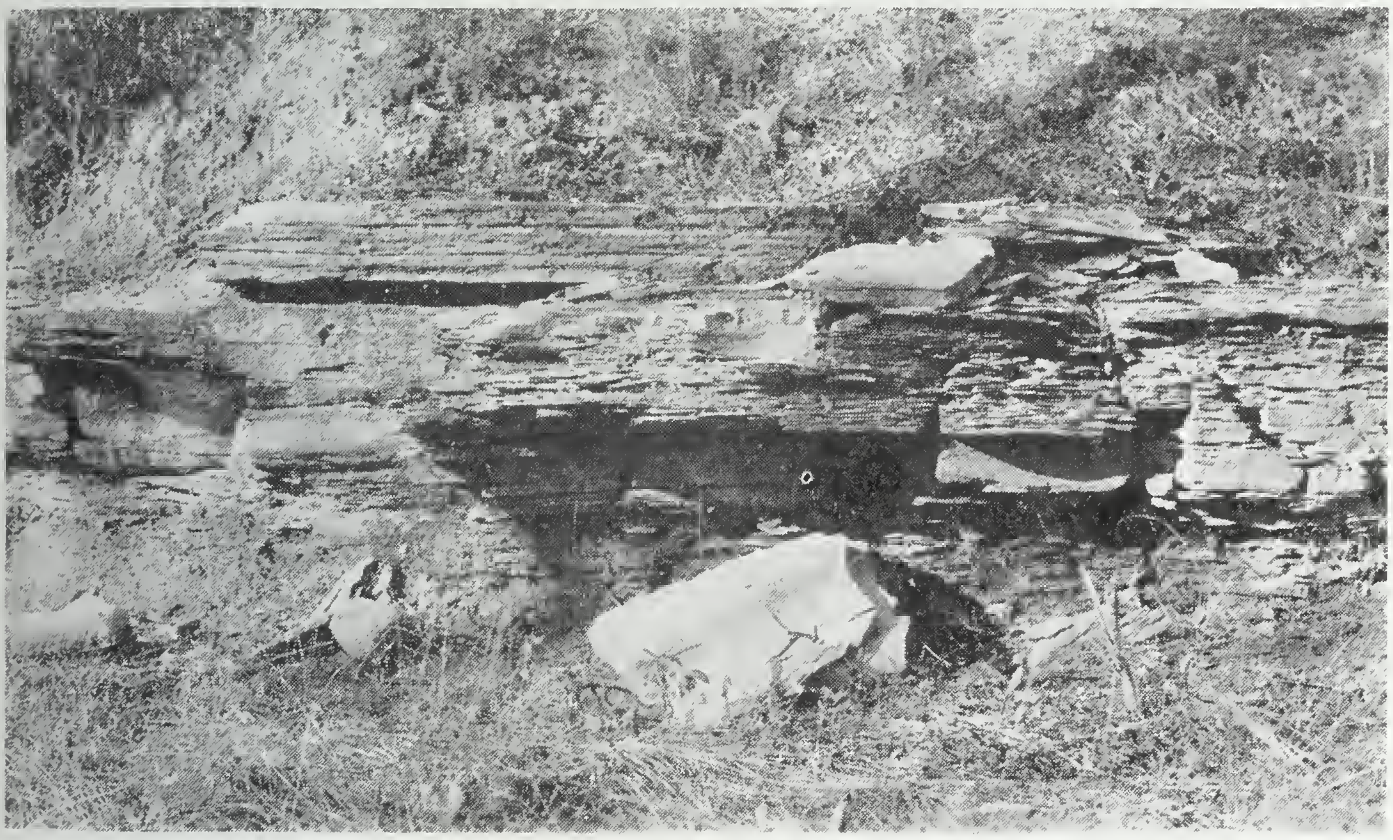

Fig. 9.—Platy, fresh-water limestone, NE. ¼ SW. ¼ sec. 13, T. 4 N., R. 5 E.

ville may be the continuation of this same bed as it occurs at approximately the same position in the stratigraphic section even though the platy limestone is undeveloped there.

Conglomerate consisting of gray limestone pebbles or nodules in a calcareous, more or less sandy and ferruginous matrix occurs at numerous places in northeastern Marion and northwestern Clay counties. In the SW. ¼ NE. ¼ sec. 4, T. 4 N., R. 5 E., a thin bed of such material occurs 4 feet above fresh-water limestone. In south central sec. 18 and north central sec. 19, T. 4 N., R. 6 E., thin beds of conglomerate occur at one or more horizons between the thin lenticular marine limestone which overlies a coal horizon, and the thick black slaty shale. Near the NW. corner of sec. 13, T. 4 N., R. 5 E., and the SW. corner of sec. 19, T. 3 N., R. 4 E., limestone conglomerate is closely associated with the Omega limestone as previously mentioned. In the SE. ¼ SE. ¼ sec. 18 of the latter township, it overlies thin-bedded sandstone which might be at a lower elevation than the Omega limestone were it present here. Well cemented conglomerate occurs by the roadside near the center W. line NW. ¼ sec. 27, T. 4 N., R. 4 E., not far below the level of the prairie. Three and one-half feet of limestone conglomerate outcrops in the N. ½ NW. ¼ sec. 5, T. 3 N., R. 4 E., unassociated with other exposures, and similar material occurs near the center sec. 15, T. 4 N., R. 5 E.

The significance of the limestone conglomerate is not known. It certainly occurs at different places at various intervals between the Omega limestone and the black slaty shale and may even be present locally below the level of the Omega limestone. At some places it strongly suggests an unconformable deposit occurring locally on an irregular surface of erosion and possibly wherever found may be of approximately contemporaneous age but at some places it appears to be an integral part of a perfectly conformable sequence. At those localities where the conglomerate is closely associated with the Omega limestone it is likely to include marine fossils and may be composed largely of pebbles derived from the Omega, but elsewhere it may consist of more or less reworked calcareous nodules similar to those present between the two sandstones near the northeast corner of sec. 9, T. 4 N., R. 5 E.

Although very erratically developed, fresh-water limestones appear to be sporadically present at a comparable horizon throughout a wide area in central and southeastern Illinois. Besides in Clay and Marion counties they have also been observed in Jasper, Richland, Edwards, White, and Jefferson counties.

BEDS OVERLYING THE FRESH-WATER LIMESTONES

The beds intervening between the fresh-water limestones and the black slaty shale are exposed with a fair degree of completeness only in the NE. ¼ sec. 9 (Fig. 10) and the SW. ¼ sec. 13, T. 4 N., R. 5 E. At the latter locality this interval is much reduced and consists mainly of shale that includes a dark *Estheria*-bearing layer in the lower part, and a thin nodular limestone layer with marine fossils less than one foot below the black shale.

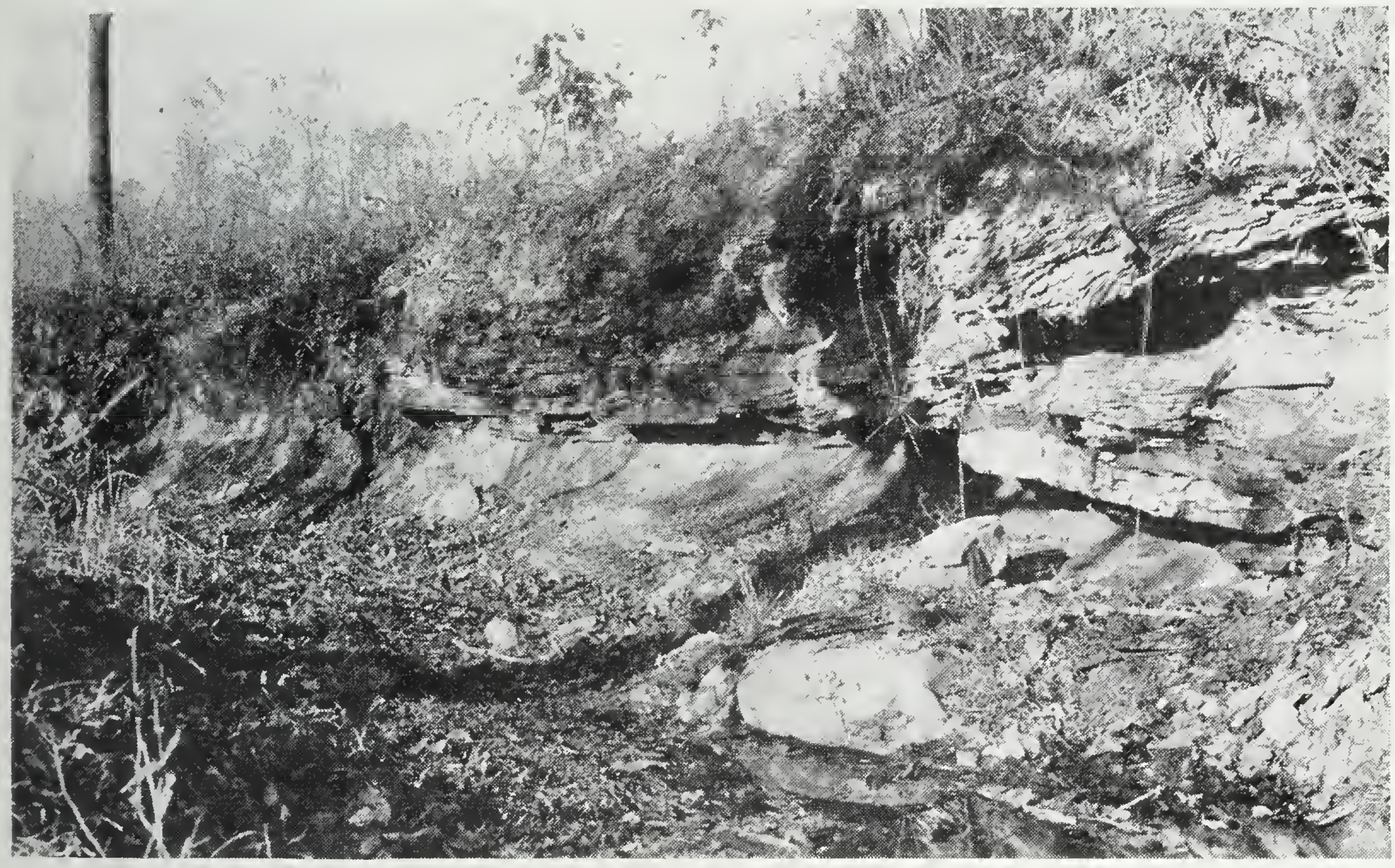

Fig. 10.—Black slaty shale and underlying beds in SE. ¼ NE. ¼ sec. 9, T. 4 N., R. 5 E. The following section is exposed here:

8. Black slaty shale........	1′6″
7. Softer black shale.......	1′
6. Black slaty shale........	1′
5. Dark gray, fine grained limestone lens..........	6″
4. Dark gray calcareous shale	8″
3. Shaly coal...............	¼″
2. Poorly developed underclay	3″
1. Fine grained sandstone..	1′6″

No. 1 contains root impressions and Nos. 4 and 5 contain marine fossils. A large oval concretion of limestone similar to No. 5 has fallen from the cavity above the hammer to the water's edge.

At the SW. corner of sec. 10 of this same township, a thin, dark gray earthy limestone with marine fossils closely underlies the thick black slaty shale. Two and one-half feet lower occurs another bed of black slaty shale more than one foot thick and coaly in its lower part with brackish-water fossils. Downstream to the northeast there appears below the limestone a lens of fine-grained calcareous sandstone that thickens to the northeast and cuts out the lower black shale. These beds appear to be equivalent to those exposed in sec. 13 but below them occurs gray, silty to sandy shale with large oval, more or less septarian limestone concretions which may reach a thickness of nearly 20 feet. This shale is unrepresented at the other locality.

In the NE. ¼ sec. 9, T. 4 N., R. 5 E. (map No. 10, Fig. 4), a thin coaly streak and poorly developed underclay a few inches thick underlies the thick slaty shale. Locally an inch of dark argillaceous limestone intervenes between the shale and coal horizon. Beneath the underclay is 3 to 4 feet of thin-bedded calcareous sandstone overlying about 20 feet of shale, sandy above with oval septarian concretions, and silty below with a few rather continuous thin bands of clay-ironstone. A small covered interval separates the lower part of this shale from the platy limestone that has previously been mentioned as occurring at this locality.

The sandstone of the last section, although thin, is probably the basal sandstone of the Macoupin cyclothem that is widespread throughout this part of the State and locally attains a considerable thickness and may become very massive. The sandstone extensively exposed north and northeast of Xenia is believed to be this same member in thicker development. Likewise the sandstone outcropping at many places in secs. 21, 30, 32, 33, and 34, T. 4 N., R. 4 E., and which becomes very massive in part of this area is also considered to be the continuation of this bed to the west. Sandstone present in sec. 29, T. 4 N., R. 3 E., is probably this same bed; it here contains a few marine fossils in a restricted very calcareous zone near the top.

Elsewhere in this part of the State the Macoupin sandstone is known to rest unconformably upon and locally to cut out a considerable thickness of underlying beds. It is probable that similar unconformable relations also exist in northwestern Clay and northeastern Marion counties although the evidence here is not conclusive. It is possible that the sandy shale overlying the Omega limestone in the NW. ¼ sec. 30, T. 3 N., R. 4 E. (map No. 74, Fig. 4), is a representation of the lower part of this member and it is probable that much of the sandstone that outcrops extensively, to the almost complete exclusion of other types of rock, south and east of this locality in Marion County is this same bed.

The limestone, coal, and underclay that normally intervene between the black slaty shale of the Macoupin cyclothem and the sandstone described above are very erratically developed in this area. Two to three inches of coal over 2½ feet of underclay occurs in the SE. ¼ sec. 18, T. 4 N., R. 6 E. Both of these members are absent in sec. 13, T. 4 N., R. 5 E. A thin zone of very shaly coal without underclay is present at the SW. corner of sec. 10, T. 4 N., R. 5 E., and several thin bands of coal totalling not more than 3 inches occur without underclay in the SE. ¼ sec. 5 in the same township (map No. 5, Fig. 4). A discontinuous smut streak without underclay is exposed in the NE. ¼ NE. ¼ sec. 32, T. 3 N., R. 5 E. (map No. 44, Fig. 4). Underclay outcropping in SE. ¼ SW. ¼ sec. 19, T. 4 N., R. 4 E. (map

No. 45, Fig. 4), probably belongs at this horizon. Coal 8 inches thick above 6 inches or more of underclay occurs near center W. line sec. 10, T. 3 N., R. 3 E. (map No. 54, Fig. 4). The coal has thickened to 14 inches in sec. 29, T. 4 N., R. 3 E. (map No. 50, Fig. 4) and overlies a foot or more of underclay. The coal apparently continues thickening westward and has been mined in a very small way near the SE. corner SW. ¼ sec. 31 of the same township and near the center of sec. 1, T. 3 N., R. 2 E.

Limestone, largely dark colored and very argillaceous occurs irregularly in thin lenses between the coal or its horizon and the overlying thick black slaty shale. It is best developed locally in the SW. ¼ of sec. 29, T. 4 N., R. 3 E., where it reaches a maximum thickness of 9 inches but pinches out entirely within 10 feet and in the W. ½ sec. 26, T. 4 N., R. 4 E. (map Nos. 46 and 47, Fig. 4), where it is one foot thick. Similar limestone lenses of less thickness have been observed in the SW. corner sec. 10, T. 4 N., R. 5 E., in the NE. ¼ sec. 32, T. 3 N., R. 5 E., the SE. ¼ sec. 36, T. 4 N., R. 4 E. (map No. 60, Fig. 4), SW. ¼ sec. 31, T. 4 N., R. 3 E. (map No. 52, Fig. 4). and near the center W. line sec. 26, T. 4 N., R. 2 E. (map No. 53, Fig. 4). This limestone was apparently encountered in the cut of the Illinois Central Railroad on the N. line sec. 7, T. 4 N., R. 5 E. (map No. 8, Fig. 4), as loose fragments occur upon the bank and it is reported to have been seen in the NW. ¼ sec. 10, T. 3 N., R. 3 E., and in the SW. ¼ sec. 23, T. 3 N., R. 5 E. (map No. 42, Fig. 4), at which latter locality it is said to overlie 6 inches of coal.[1]

BLACK SLATY SHALE

The black slaty shale of the Macoupin cyclothem is one of the most widespread and persistent strata of the Pennsylvanian succession exposed in central Illinois. Its outcrops south of Crooked Creek in Clay County between sec. 21, T. 4 N., R. 6 E., and sec. 5, T. 4 N., R. 5 E., are too numerous to list; the locations of the more important outcrops are indicated as datum points on the accompanying structural contour map (Fig. 4, Table 2). To the north it has been observed in the west bank of Little Wabash River near center E. line NE. ¼ sec. 30, T. 5 N., R. 6 E., and is reported to have been encountered in a shallow well some distance to the northwest, probably at a somewhat higher elevation. Throughout this area the black slaty shale reaches the extraordinary thickness of from 4 to 7 feet. It is a black, highly carbonaceous, well laminated shale that weathers into thin more or less elastic flakes or sheets. It is practically unfossiliferous except for conodonts and at many places contains large oval concretions up to several feet in diameter of very hard, fine-grained, dark gray, argillaceous and carbonaceous limestone.

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[1] Worthen, A. H., Geological Survey of Illinois, vol. VI, 1875, p. 92.

In the NE. 1/4 sec. 32. T. 3 N., R. 5 E. (near map No. 44. Fig. 4), the slaty shale is 2 feet thick and it attains a similar thickness in the SE. 1/4 sec. 36. T. 4 N., R. 4 E. (map No. 60. Fig. 4). In the W. 1/2 sec. 26 of the same township (map Nos. 46 and 47. Fig. 4) this bed is about 3 feet thick. The black slaty shale was excavated in the cut on the Illinois Central Railroad on the N. line NE. 1/4 sec. 7. T. 4 N., R. 5 E. (map No. 8. Fig. 4) and fragments occur on the bank but its thickness here is not known. This member is entirely absent above the coal near the center of the W. line sec. 10. T. 3 N., R. 3 E. (map No. 55. Fig. 4). In sec. 29, T. 4 N., R. 3 E. (near map No. 50. Fig. 4), the slaty shale varies in short distances from nothing to 1½ feet thick and in general is undeveloped where the limestone lenses are present above the coal. One and one-half feet of black slaty shale overlies the coal in SW. 1/4 sec. 31. of the same township (map No. 51. Fig. 4).

There may be some question regarding the correctness of the correlation of the thick slaty shale and associated beds along Crooked Creek with the coal and slaty shale southwest of Kinmundy and the coal without slaty shale northeast of Brubaker. However, the evidence furnished by the outcrops, not only of the area under particular consideration but also of several adjacent counties, makes it appear that this correlation is most probable.

BEDS OVERLYING BLACK SLATY SHALE

Limestone to a maximum thickness of 5 feet which is rather massive, fine-grained, somewhat argillaceous, gray when fresh but weathering to light buff color, locally overlies the black slaty shale in the SE. 1/4 sec. 29 and NE. 1/4 sec. 32, T. 3 N., R. 5 E. (map Nos. 43 and 44, Fig. 4), and the W. 1/2 sec. 26. T. 4 N., R. 4 E. (near map No. 47. Fig. 4). Elsewhere the slaty member is overlain by a considerable thickness of shale which is gray and slightly silty southwest of Kinmundy and south of Crooked Creek in secs. 17 and 18. T. 4 N., R. 6 E. At the latter locality marine fossils are sparingly present to a height of 20 feet above the black slaty shale. Twenty-five feet of shale at this position is exposed in the railroad cuts in sec. 7. T. 4 N., R. 5 E., the upper half becomes increasingly sandy above and similar material is present in another railroad cut in sec. 31 to the south.

MASSIVE FRIABLE SANDSTONE

The youngest Pennsylvanian rock of Clay and Marion counties is more or less massive, very soft and friable sandstone which is brownish where weathered and is commonly coarser grained than the other sandstones of the region. It is well exposed in the road-cuts near the top of Oak Mound in the SE.1/4 sec. 23. and NE. 1/4 sec. 26. T. 3 N., R. 5 E., and by the roadside in NE. 1/4 sec. 13. T. 4 N., R. 4 E. Possibly the soft massive sandstone in the railroad cut near the N. line of sec. 31. T. 4 N., R. 5 E., occurs at this same horizon. It is also probable that this sandstone occurs elsewhere in some of the higher portions of this area as for example the SW. ¼ sec. 5 and NW. ¼ sec. 8, T. 4 N., R. 5 E., but because of its softness it is rarely exposed except in road-cuts.

This friable sandstone is believed to be equivalent to the Merom sandstone of the Wabash valley which, so far as known, is the youngest Pennsylvanian bed present in Illinois. The Merom sandstone is unconformable with the older beds below it, and if the correlation suggested above is correct, several cyclothems normally present above the Macoupin have been entirely removed from this region by pre-Merom erosion.

GENERAL OBSERVATIONS

The Pennsylvanian section is much thicker in southern Illinois than in the western and eastern parts of the State. This thickening is the result not only of the southward thickening of individual members of the succession but also of the introduction of numerous additional members not present on the other flanks of the basin. In southern Illinois where these additional members are, in general, best developed they commonly form parts of more or less well characterized cyclothems. As they are traced northward these cyclothems, which are not present between the more widespread cyclothems of western and eastern Illinois, gradually lose their identity and pass into more or less complex successions of rudimentary members that are extremely difficult to recognize and correlate. Because the central part of the Illinois Basin was depressed much more during Pennsylvanian time than were its flanks, such successions continue as tongue-like extensions much farther north in the central part of the State than they do either to the west or east.

The complex succession of beds, including fresh-water limestones and probably several coal horizons, which intervenes between the Omega limestone and black slaty shale in Clay and Marion counties apparently represents a series of beds, such as those described above, which rapidly expands and integrates to the south. It is likely that other comparable intervals occur in the unexposed lower part of the Pennsylvanian strata of this area which produce thickening of the section eastward from Sandoval and Centralia and make the identification and correlation of the members penetrated by the deep wells of the area impossible from the records that are available.

APPENDIX I

WELL LOGS

Logs Nos. 1, 2, and 4 are driller's logs of the deeper wells and Log No. 6 is the log of a mine shaft in the area shown in figure 4. Logs Nos. 3 and 5 are sample study logs of wells outside of but near the area shown in figure 4, included however within the area of figure 2. Other logs referred to in this report are in the files of the State Geological Survey, and copies of them may be borrowed upon application to the Chief, State Geological Survey, Urbana, Illinois.

The logs given are as follows:

Log. No.	Company and well	Map No. (Fig. 2)	Map No. (Fig. 4)
1	Benedum Trees and Grayson J. H. Harrell well No. 1	2	30
2	Benedum Trees Anderson well No. 1	3	41
3	Amber Oil and Gas Co. Curry well No. 1	4	...
4	Ohio Oil Co. H. B. Henninger well No. 1	62	(*a*)
5	Benoist and Finn Finn well No. 1	70	...
6	Kinmundy shaft	...	49

(*a*) On map but unnumbered because it did not furnish a datum point.

1. Benedum Trees and Grayson, J. H. Harrell well No. 1, NE. corner sec. 27, T. 4 N., R. 5 E., Clay County

Driller's log

Elevation 534 feet

Map. No. 2, Fig. 2
Map No. 30, Fig. 4

	Thickness *Feet*	Depth *Feet*
Pleistocene system		
Soil, dark, soft	24	24
Pennsylvanian system		
Lime, light, hard (fresh-water limestone?)	4	28
Shale, light, soft	22	50
Lime, light, hard (Omega limestone?)	3	53
Slate, light, soft	77	130
Sand, broken, soft	30	160
Slate, dark, medium	5	165
Sand, broken, light, medium	155	320
Slate, dark, soft	80	400
Sand, broken, medium	10	410
Slate, dark, soft	20	430
Sand, broken, light, medium	40	470
Slate, dark, soft	30	500
Sand, broken, light, medium	50	550
Slate, light, medium; 1 bailer water per hour at 580	30	580
Sand, light, medium	10	590
Lime, light, hard	30	620
Slate, dark, medium	115	735
Sand, broken, light, medium; hole full water	15	750
Sand, light, medium	45	795
Slate, dark, soft	50	845
Sand, broken, light, medium	30	875
Slate, dark, soft	75	950
Lime, light, hard	10	960
Slate, dark, soft	40	1000
Coal, black, soft	2	1002
Lime, light, hard	8	1010
Slate, dark, soft	12	1022
Slate, light, medium	63	1085
Coal, black, soft	4	1089
Slate, light, soft	96	1185
Slate, dark, medium	185	1370
Slate, light, medium	15	1385
Slate, dark, soft	65	1450
Shale, light, medium	10	1460
Slate, dark, soft	65	1525
Sand, light, medium; 1 bailer water at 1535, 2 bailers at 1553, hole full at 1560-1700, 3 bailers at 1735, hole filled up, 500 feet in 30 minutes at 1800	175	1700
Lime, light, hard	15	1715
Water, sand, light, medium	20	1735
Lime, broken, dark, medium	40	1775
Slate, dark, soft	15	1790
Sand, brown, soft	5	1795
Sand, water, light, soft	10	1805
Sand, light, hard	25	1830
Sand, water, light, soft	50	1880
Sand, pebbles, light, hard; and lime, sandy, very nice looking	20	1900

	Thickness *Feet*	Depth *Feet*
Mississippian system		
Chester series		
Lime, gritty, light, hard	10	1910
Slate, dark, soft	6	1916
Lime, sandy, light, hard	24	1940
Slate, and shells, light, medium	14	1954
Slate, dark, soft	14	1968
Lime, light, hard	7	1975
Slate, dark, soft	15	1990
Lime, light, firm	30	2020
Slate, light, soft	5	2025
Slate, light, medium	15	2040
Slate, light, soft	20	2060
Lime, light, hard	6	2066
Slate, dark, soft	6	2072
Lime, light, medium	2	2074
Slate, dark, soft	36	2110
Lime, light, hard	12	2122
Slate, light, soft	13	2135
Sand, water, light, medium; show of black oil at 2145-2152. Hole filled up with water at 2152 and started caving. Underreamed 6⅝, 1945-2202	17	2152
Sand, light, hard	20	2172
Slate and shells, dark, soft	27	2199
Lime, light, hard	10	2209
Slate and shells, dark, soft	39	2248
Lime, light, hard	5	2253
Slate, red, soft	1	2254
Slate, light, soft	162	2270
Slate, red, light, soft	5	2275
Slate, light, soft	7	2282
Lime, light, hard	6	2288
Slate, dark, soft	9	2297
Lime, light, medium	5	2302
Abandoned. 16″—24; 12½″—435; 10″—1022; 8¼″—1707; 6⅝″—1942; 6⅝″ underreamed to 2302.		

2. Benedum Trees, Anderson well No. 1, SE. ¼ NW. ¼ sec. 15, T. 3 N., R. 5 E. Driller's log

Elevation 541 feet

Map No. 3, Fig. 2
Map No. 41, Fig. 4

	Thickness *Feet*	Depth *Feet*
Pleistocene system		
Soil, yellow, soft; water at 26 feet	27	27
Pennsylvanian system		
Coal, black soft (*a*)	3	30
Slate, dark, soft	15	45
Slate, light, medium	95	140
Sand, light, medium	45	185
Slate, light, soft	10	195
Lime, light, hard	15	210
Broken sand, light, soft	60	270
Slate, blue, soft	90	360
Lime, light, hard	3	363
Slate, dark, soft	27	390
Lime, gritty, brown, hard	8	398
Slate, dark, soft	32	430
Lime, dark, hard	12	442
Slate, dark, soft	8	450
Lime, sandy, light, medium	20	470
Slate, dark, soft	68	538
Sand, light, medium	6	544
Slate, light, soft; 10 bailers water at 575	6	550
Slate, dark, soft	10	560
Sandy shale, light, medium	70	630
Slate, dark, medium	30	660
Lime, light, hard	6	666
Slate, dark, soft	10	676
Slate, light, soft	19	795
Sand, light, soft; water	20	815
Slate, light, soft	23	838
Sand, light, soft	20	858
Lime, light, hard	6	864
Slate, light, soft	136	1000
Lime, dark, hard	15	1015
Slate, light, medium	5	1020
Lime, light, hard	5	1025
Coal, black, soft	4	1029
Slate, dark, soft	3	1032
Lime, light, firm	8	1040
Lime, gritty, light, firm	20	1060
Slate, dark, medium	15	1075
Coal, black, soft	6	1081
Slate, light, soft	5	1086
Slate, dark, soft	14	1100
Sand, light, medium	10	1110
Lime, light, hard	13	1123
Slate, dark, soft	30	1153
Lime, light, medium	7	1160

(*a*) Probably the black slaty shale. Depth to Omega limestone horizon calculated by adding the interval of 57 feet (found at the Dayton school well, map No. 39, Fig. 4, two miles east-northeast) to 27 feet, or a total of 84 feet (Table 2). It is assumed that the Omega limestone either is absent or was not recorded by the driller.

	Thickness *Feet*	Depth *Feet*
Slate, dark, soft	15	1175
Sand, broken, medium	65	1240
Slate, light, soft	3	1243
Lime, sandy, light, medium; water at 1263	20	1263
Sand, light, soft; hole full	82	1345
Slate, dark, soft	10	1355
Slate, light, soft	10	1365
Lime, sandy, light, hard; water at 1375	6	1371
Sand, light, medium	29	1400
Slate, light, medium	15	1415
Slate, dark, soft	25	1440
Lime, light, hard	10	1450
Slate, light, medium	10	1460
Slate, dark, soft	15	1475
Slate, light, soft	10	1485
Slate, dark, soft	10	1495
Sand, light, medium	10	1505
Slate, dark, soft	15	1520
Sand, broken, light, medium	15	1535
Sand, light, soft	15	1550
Slate, dark, soft	25	1575
Slate, light, soft	10	1585
Lime, light, medium	20	1605
Sand, light, soft; similar to water sand	8	1613
Sand, light, medium	25	1638
Slate, dark, soft	2	1640
Lime, light, hard	4	1644
Slate, dark, soft	16	1660
Sand, broken, light, medium	52	1712
Sand, light, soft; water	30	1742
Lime, light, hard	18	1760
Sand, light, medium	24	1784
Lime, sandy, light, hard	16	1800
Coal, black, soft	2	1802
Lime, light, medium	3	1805
Slate, dark, soft	60	1865
Lime, light, hard	10	1875
Sand, light, soft	15	1890
Lime, gritty, light, hard	15	1905
Sand, light, medium	25	1930
Mississippian system		
Chester series		
Slate, light, medium	15	1945
Lime, light, hard	20	1965
Lime, pebbles, light, medium	8	1973
Slate, dark, soft	7	1980
Lime, light, hard	25	2005
Slate, light, soft	10	2015
Lime, light, hard	5	2020
Slate, light, medium	7	2027
Slate, dark, soft	13	2040
Sand, dark, medium	6	2046
Slate, dark, soft	10	2056
Sand, light, medium	4	2060
Slate, dark, soft; water	10	2070
Sand, light, soft	6	2076

3. Amber Oil and Gas Company, Curry well No. 1, NW. ¼ SW. ¼ sec. 16, T. 2 N., R. 7 E., Clay County

Compiled from driller's log and sample study by L. E. Workman (*a*)

Elevation 431 feet

Map No. 4, Fig. 2

	Thickness *Feet*	Depth *Feet*
Pleistocene system		
Soil and glacial till	20	20
Pennsylvanian system		
"Shale"	25	45
Sandstone, light gray, very fine; "fresh water"	63	108
Sandstone, calcareous, light gray, very fine, compact	12	120
"Sandstone; fresh water"	25	145
Shale, sandy, gray; "set 12½-inch casing at 150 feet"	7	152
Coal; fireclay; sandstone, very fine	2	154
"Shale"	17	171
Sandstone, calcareous, light gray, very fine, coarse at base, porous; "fresh water to ground level"	77	248
Shale, black, brittle; "reset 12½-inch casing at 251 feet"	3	251
Coal; fireclay; grades down to marl, light gray, sandy at base	19	270
Sandstone, calcareous, light gray, very fine	12	282
Sandstone, argillaceous, grading to shale, sandy, gray	34	316
Shale, gray, partly sandy	68	384
Limestone, light brown, coarse, fossiliferous	4	388
Shale, silty, gray	27	415
Sandstone, calcareous, light gray, very fine	5	420
Shale, silty, light to dark gray	75	495
Sandstone, calcareous, light brown, compact; shale, calcareous, dark gray	15	510
Shale, silty, dark gray, tough	45	555
Siltstone, gray, grading to sandstone, very fine	45	600
Limestone, buff, fossiliferous; shale, black, fossiliferous, at top	8	608
Bone coal	2	610
Fireclay; sandstone, carbonaceous, very fine	6	616
"Shale, light"	100	716
Sandstone, calcareous, fine, porous; "salt water to about 175 feet from top of casing"	57	773
Same; with shale, gray and black, at top; "salt water to about top of casing"	24	797
Limestone, buff and light gray, fossiliferous; "set 10-inch casing at 800 feet"	10	807
"Shale, light to gray and black"	183	990
"Limestone"	5	995
"Sandstone; about four bailers water per hour"	10	1005
"Limestone, dark gray, flinty"	7	1012
Shale, carbonaceous, black, brittle; coal	7	1019
"Shale, gray to black"	61	1080
Shale, silty, gray, containing siderite concretions; grades to siltstone	90	1170
Shale, green and gray, smooth, weak (red rock horizon)	34	1204
Coal	2	1206
Shale, silty, brownish-gray, tough	26	1232
Sandstone, shaly, light gray, fine; "dry"	4	1236

(*a*) Quotations are from driller's log.

	Thickness *Feet*	Depth *Feet*
Shale, silty, dark gray, tough	39	1275
Sandstone, calcareous, light gray, fine, coaly; below 1295 feet struck "heavy flow of salt water to within 175 feet from top"	50	1325
Shale, gray, weak; limestone, buff	5	1330
Shale, dark and light gray; "set 8¼-inch casing at 1338 feet"	9	1339
Shale, silty, gray, tough, siderite concretions	52	1391
Sandstone, calcareous, light gray, very fine, "dry to 1432 feet, salt water below"	72	1463
Sandstone, as above; and shale, silty, dark gray	37	1500
Sandstone, buff, very fine to medium	58	1558
Same; interbedded with siltstone and shale, dark gray	17	1575
Shale, dark gray	11	1586
Sandstone, buff, very fine	12	1598
Coal; shale, dark gray; sandstone, very fine, carbonaceous, compact	5	1603
Sandstone, light gray, very fine	6	1609
Coal; sandstone, light gray, very fine, compact to loose; shale	9	1618
Sandstone, buff, fine, porous; "salt water"	94	1712
"Red shale; coal band"	2	1714
Sandstone, buff, fine to medium, porous	33	1747
Siltstone, grading to shale, dark gray, tough	44	1791
Sandstone, buff, fine, porous, partly calcareous	134	1925
Shale, dark gray, smooth, tough; siltstone below	48	1973
Sandstone, calcareous, light gray, compact; "set 6⅝-inch casing at 1978 feet"	14	1987
Sandstone, buff, fine, grading to coarse downward, porous; "salt water"	147	2134
Mississippian system		
Chester series		
Clore formation		
Shale, calcareous, greenish to pinkish-gray	3	2137
Shale, dark bluish-gray; sandstone, calcareous, very fine, compact	23	2160
Palestine sandstone		
Sandstone, calcareous, light buff, very fine; "dry"	24	2184
Siltstone, calcareous, light gray, tough; shale, dark gray	11	2195
Shale, bluish-gray, tough; siltstone	6	2201
Sandstone, calcareous, light gray, very fine, compact	11	2212
Sandstone, as above, grading to siltstone and shale, dark gray	15	2227
Menard formation		
Limestone, gray; shale, dark gray	8	2235
Shale, dark gray; few limestone beds	58	2293
Shale, dark gray; thin siltstone and limestone beds; "set 5 3/16-inch casing at 2323 feet"	108	2401

4. Ohio Oil Company, H. B. Henninger well No. 1, SW. corner SE. ¼ SE. ¼ sec. 25, T. 3 N., R. 4 E., Marion County, Illinois

Driller's log

Elevation 522 feet

Map No. 62, Fig. 2

	Thickness *Feet*	Depth *Feet*
Pleistocene system		
Clay	19	19
Pennsylvanian system		
Lime	2	21
Slate	35	56
Sand rock	84	140
Shale	120	260
Lime	10	270
Slate	180	350
Sand rock	3	353
Slate	92	445
Sand rock	2	447
Salt water	...	....
Slate	...	489
Lime	26	515
Slate	25	540
Lime	2	542
Slate	65	605
Lime	5	610
Slate	20	630
Lime	18	648
Shale	27	675
Lime	35	710
Shale, brown	15	725
Sandy lime	25	750
Shale, light	40	790
Lime	6	796
Sand rock	39	835
Shale, black	70	905
Lime	8	913
Slate	107	1020
Lime	30	1050
Coal No. 6	6	1056
Lime	44	1100
Shale	45	1145
Part coal	5	1150
Sandy lime	20	1170
Sand lime	70	1240
Salt sand	30	1270
Lime	25	1295
Slate	10	1305
Slate and lime	135	1440
Salt sand	60	1500
Sand	40	1540
Slate	55	1595
Lime shale	20	1615
Slate	15	1630
Salt sand	40	1670
Slate	20	1690
Shale, black	10	1700
Salt sand	95	1795
Slate	45	1840
Salt sand	61	1901
Hard sand	9	1910

	Thickness *Feet*	Depth *Feet*
Mississippian system		
Chester series		
Shale	10	1920
Lime	5	1925
Shale	10	1935
Slate	17	1952
Sand	73	2025
Lime	10	2035
Slate	59	2094
Sand shale	3	2097
Lime	23	2120
Slate	93	2213

5. Benoist and Finn, Finn well No. 1, SE. ¼ NE. ¼ sec. 16, T. 1 N., R. 3 E., Marion County

Compiled by L. E. Workman from driller's log and sample studies of Pennsylvanian by G. H. Cady and of Chester by M. A. Blair

Elevation 581 feet

Map No. 70, Fig. 2

	Thickness *Feet*	Depth *Feet*
Pleistocene system		
Loess and clay	10	10
Sand, yellow, fine	5	15
Glacial till	10	25
Sand, yellow, fine, clayey	4	29
Pennsylvanian system		
Shale, very silty, gray	26	55
Sandstone, light gray, fine	40	95
Siltstone, light gray	25	120
"Coal"	1	121
Shale, silty, light gray	4	125
Sandstone, light gray, fine	37	162
Shale, silty, light gray	8	170
Shale, dark gray, hard	5	175
Shale, light gray, slip-fractured	10	185
Shale, gray, slaty	10	195
Sandstone, calcareous, fine; clay, weak, "clod"; coal	5	200
Shale, light gray	15	215
Shale, gray, slaty	18	233
"Sandstone"	22	255
"Shale"	9	264
Limestone, light and dark gray	4	268
Coal and fireclay	2	270
Fireclay	5	275
Shale, light gray, ironstone concretions	40	315
Shale, dark gray, hard	5	320
"Shale"	6	326
Limestone, sandy, coarse; bone coal	4	330
Shale, light gray, hard	30	360
Sandstone, calcareous, light gray; limestone, light brown; coal	5	365
Shale, light to dark gray, some greenish at 380-395	92	457
Limestone, fossiliferous; siltstone, light gray	6	463

5. Benoist and Finn, Finn well No. 1—*continued*

	Thickness *Feet*	Depth *Feet*
Shale, light to dark gray	77	540
Limestone, white, fine; shale, dark gray, at base	13	553
"Coal"	2	555
Shale, black, hard	5	560
Shale, light gray	100	660
Sandstone, light gray, fine, calcareous at base	45	705
Sandstone, light gray, medium to coarse	20	725
Shale, dark gray, hard	10	735
Shale, light gray	10	745
Sandstone, calcareous, light gray, fine	10	755
Shale, light gray	125	880
Shale, reddish brown; "red rock"	5	885
Limestone, buff, white, and green; shale, red, green, and gray; little coal	4	889
Shale, dark gray to black; sandstone, calcareous, gray	11	900
Shale, gray and green; limestone, sandy	4	904
Coal	5	909
Fireclay	5	914
Limestone, light buff to cream, fine	9	923
Shale, gray	12	935
Shale, sandy, light gray, hard	8	943
Sandstone, light gray, fine, compact	17	960
Shale, black, hard; little coal	5	965
Fireclay; sandstone, gray, fine, calcareous	12	977
Limestone, gray, white, and brown, *Fusilina*	3	980
Coal	7	987
Fireclay	3	990
Limestone, white, fine, "sandy"	3	993
Shale, light to dark gray, hard	52	1045
Sandstone, gray, compact, finely laminated, carbonaceous partings	58	1103
"Shale"	12	1115
Sandstone, as above, grading down to loose	31	1146
Siltstone, gray	4	1150
Shale, black; limestone, brown and black, fossiliferous; little coal	5	1155
Siltstone, light gray	5	1160
Sandstone, gray. fine	5	1165
Shale, black	5	1170
Sandstone, gray, fine	40	1210
Shale, dark gray to black, brownish below	15	1225
Shale, light gray, soft, slip-fractured	5	1230
Same; and bone coal	5	1235
Shale, black, hard, carbonaceous	10	1245
Shale, carbonaceous, slip-fractured	5	1250
Sandstone, gray, fine	5	1255
Shale, black, light gray at top	13	1268
Coal	2	1270
Fireclay, slip-fractured	5	1275
Siltstone, gray and brownish; calcareous below	5	1280
Limestone, gray, white, and greenish, dense fossiliferous	3	1283
Sandstone, calcareous, dark gray to black, dense	12	1295
Shale, black; coal	5	1300
Sandstone, fine; fireclay, slip-fractured, at top	10	1310
Sandstone, fine, interbedded with shale, dark, hard	33	1343
Clay, light and dark gray, slip-fractured	12	1355
Sandstone, gray and reddish	5	1360
Siltstone, dark gray to black, grading down to shale	8	1368
Sandstone, white, fine	37	1405
Shale, gray; clay, slip-fractured	5	1410
Clay, slip-fractured; little limestone, brown, coarse	5	1415

5. Benoist and Finn, Finn well No. 1—*concluded*

	Thickness *Feet*	Depth *Feet*
Shale, calcareous, dark gray, micaceous	5	1420
Sandstone, white, fine	25	1445
Siltstone, gray	5	1450
Sandstone, white, fine, clean	55	1505
Sandstone, white, very fine	30	1535
Sandstone, white, fine	15	1550
"Slate"	5	1555
Sandstone, brownish to white, fine	57	1612
Shale, dark gray, carbonaceous, slip-fractured	13	1625
Shale, silty, dark gray, interbedded with sandstone, grading to sandstone	60	1685
Sandstone, light gray, very fine to fine, "water"	145	1830
Mississippian system		
Chester series		
Clore formation		
Shale, silty, light greenish-gray to red rock at base	18	1848
Palestine formation		
Shale, dark greenish-gray; interbedded with siltstone and sandstone, very fine	27	1875
Menard formation		
Shale, dark gray	10	1885
Limestone, dark gray, very fine to coarse; interbedded with shale, dark gray	45	1930
Shale, dark gray to green; thin beds limestone and sandstone	60	1990
Limestone, sandy, gray; shale, sandy, gray	25	2015
Tar Springs sandstone		
Sandstone, calcareous, light gray, very fine, compact; shale at base	25	2040
Sandstone, greenish-gray, very fine, compact; shale, red and green	10	2050
Sandstone, gray, very fine, "hole full of water, still in sandstone at bottom"	6	2056

6. Kinmundy shaft, NE. ¼ NW. ¼ sec. 23, T. 4 N., R. 3 E., Marion County (*a*)

Map No. 49, Fig. 4

Elevation 602 feet

	Thickness		Depth	
	Feet	*Inches*	*Feet*	*Inches*
Soil and clay	12	..	12	..
Sandstone	46	..	58	..
Gray "slate"	18	..	76	..
Black "slate"	10	..	86	..
Sand shale	19	..	105	..
"Slate and soapstone"	4	..	109	..
Sand shale	9	..	118	..
Gray "slate"	2	..	120	..
Sandstone, hard	1	..	121	..
Gray "slate"	7	..	128	..
Sand rock, hard	4	..	132	..
"Slate"	5	..	137	..

(*a*) This log was compiled from two original logs, both labeled "Kinmundy shaft." One of these logs was published in Illinois State Geological Survey Cooperative Mining Series Bulletin 11, 1922, pp. 128-129. However the other log gives greater detail in the upper part of the section which is important for correlation with outcropping beds and is therefore substituted down to depth 143 feet in the above compilation. It is possible that one log is for the hoisting shaft and the other for the air shaft. The "limestone conglomerate" from depth 142 feet to 143 feet in one log may be the same bed as the pebbly limestone from 146 feet 5 inches to 147 feet 9 inches in the other.

6. Kinmundy shaft—*continued*

		Thickness		Depth	
		Feet	*Inches*	*Feet*	*Inches*
Sand rock, hard		2	..	139	..
Gray "slate"		3	..	142	..
Limestone conglomerate		1	..	143	..
* * * * * *					
Limestone, pebbly		1	4	147	9
"Slate," black		9	7	157	4
Coal		1	2	158	6
Fireclay		7	..	165	6
Shale, gray		19	7	185	1
"Slate," black		11	..	196	1
Coal		1	6	197	7
Fireclay		2	..	199	7
Shale		37	10	237	5
"Slate," black		5	..	242	5
Limestone, bituminous		2	..	244	5
Coal		..	6	244	11
Limestone and black shale		6	..	250	11
Coal		..	2	251	1
Clay shale		5	6	256	7
Shale, gray and black with bands of lime		51	..	307	7
"Slate," black		1	5	309	1
Coal		1	..	310	..
Fireclay		1	6	311	6
Limestone		3	..	314	6
Shale, gray		15	9	330	3
"Slate," black		3	..	333	3
Coal		2	..	333	5
Fireclay		2	10	336	3
Shale and sandstone		65	6	401	9
Coal		..	4	402	1
Fireclay		4	..	406	1
Limestone		3	..	409	1
Shale		71	..	480	1
Limestone		9	10	492	..
Shale, bituminous, and 2 inches coal		2	..	494	..
Shale, pebbly		5	..	499	..
Sandstone and shale		76	..	575	..
Limestone, pebbly		1	6	576	..
Shale, bituminous, and ½ inch coal		2	6	579	..
Fireclay		5	..	584	..
Sandstone and shale		69	..	653	..
Shale, black		..	10	653	10
Coal		..	7	654	5
Fireclay		2	..	656	5
Limestone, sandstone and fireclay		8	6	664	11
Shale, blue		14	2	689	1
Limestone		21	6	710	7
Fireclay		2	..	712	7
Shale, green		1	6	714	1
Limestone, pebbly		6	..	720	1
Sandstone and shale		84	2	804	3
Coal No. 7		2	..	806	3
Fireclay		11	..	817	3
Sandstone and shale		30	..	847	3
Coal	No. 6	2	2	849	3
Shale, black		3	..	852	5
Hard rock, gray limestone		4	..	856	5
Coal		4	2	860	7

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M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 41

I. SMOKELESS BRIQUETS: IMPACTED WITHOUT BINDER FROM PARTIALLY VOLATILIZED ILLINOIS COALS

Progress Report of a Laboratory Investigation

II. SMOKE INDEX: A QUANTITATIVE MEASUREMENT OF SMOKE

BY

R. J. PIERSOL

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PREFACE

In 1931 in planning a research program to improve the utilization of Illinois coal, one problem which presented itself was the processing of slack coal into a product which would extend its marketability and value. Success in such a project would be of importance to the State, since it would provide a better domestic fuel from its own resources, and would promote the development of the coal industry of the State, since approximately one-half of the sized coal produced in Illinois is slack coal (less than 2 inches) which offers problems of marketing for many mines, particularly during certain seasons of the year.

The experimental investigation was begun along the line of briquetting slack coal without a binder. A binder, such as tar, is not only expensive, costing approximately 70 cents per ton of briquets, but it also adds to the smokiness of the resultant fuel.

Preliminary attempts were made to briquet Illinois coals without binder by heating and applying steady pressure, but this method did not show promise of commercial success, as noted in the first part of Report of Investigations No. 31. However a systematic investigation of the combined effect of heating and impact blow, rather than steady pressure, yielded excellent briquets, without binder. This was reported in the second part of Report of Investigations No. 31 and in Report of Investigations No. 37.

Still later it was discovered that this same process could be used in making smokeless briquets without binder, by first removing the smoke producing constituents from the coal. If common binder were used the resultant briquet would not be smokeless.

The term smokeless, as used in this report, is used in the trade sense. The trade designates certain low volatile bituminous coals, like those occurring in certain beds in West Virginia and adjacent states, as smokeless. They are not truly smokeless, but by the ordinary processes of combustion they yield relatively little smoke as compared with high volatile bituminous coals. In view of this common usage of the term smokeless, the same term is used for products made from high volatile bituminous coals which yield the same amount of smoke as, or less smoke than, the so-called smokeless coals.

In the progress of the work it became desirable to develop a laboratory method for a quantitative measurement of the amount of smoke liberated in combustion in order to permit comparison of the smokiness of impact briquets made from coal with partial volatilization with that of the corresponding raw coals. This method is herein referred to as the *smoke index* method. The smoke index method made it possible later to determine the degree of volatilization of the coal necessary to make smokeless briquets.

Part I of this preliminary report deals with smokeless briquets made by impact without binder from partially volatilized Illinois coals.

Part II deals with the smoke index method and its application to the measurement of smoke in naturally occurring and in processed coals.

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I. SMOKELESS BRIQUETS: IMPACTED WITHOUT BINDER FROM PARTIALLY VOLATILIZED ILLINOIS COALS

Progress Report of a Laboratory Investigation

R. J. PIERSOL

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I. SMOKELESS BRIQUETS: IMPACTED WITHOUT BINDER FROM PARTIALLY VOLATILIZED ILLINOIS COALS

Progress Report of a Laboratory Investigation

CHAPTER I—SUMMARY

SMOKELESS BRIQUETS may be made from prepared Illinois smokeless coal fines from which 15 per cent of the volatile matter (dry basis) has been driven off, with the same briquetting equipment and the same magnitude of impact as briquets made from raw coal, using no artificial binder. The briquetting temperature of the prepared smokeless fines, however, must be between 300° and 400°C. as contrasted to a temperature of 250°C. for the natural coal fines.

The mechanical strength of smokeless briquets, as determined by tumbling tests, is slightly greater than that of briquets made from raw coal by the impact method, using optimum conditions for both.

Actual power consumption during commercial production can be determined only by commercial scale production. However, the impact energy necessary to make one ton of briquets could be supplied by 50 pounds of coal, if the coal is so burned as to produce one horsepower-hour for each two pounds of coal. In order to drive off the desired 15 per cent volatile matter (dry basis), the coal must be preheated up to a temperature of about 900°F. (483°C.). Thus, with the above combustion efficiency, it may be calculated that in general about 150 pounds of coal are required for preheating one ton of smokeless briquets. These calculations are dealt with more fully on pp. 29-30.

CHAPTER II—INTRODUCTION

NEED FOR SMOKELESS FUEL

There is a special need for a cheap smokeless domestic fuel, particularly in the Middle West. While modern stoker equipment has been rather widely employed in industry, with the result that the destructive and harmful effects of smoke from industrial plants have been considerably reduced, yet in the domestic field much less has been accomplished. Estimates based upon a recent survey[1] made in Chicago are that the smoke produced by the domestic group in Chicago since 1911 has increased ninefold for 302,000 homes and four-flat apartments, and sixteenfold for 16,000 six-flat or larger apartments. At present, according to this report, 63 per cent of the smoke in Chicago is produced by the domestic furnace, notwithstanding the fact that it consumes only 49 per cent of the coal.

It is a difficult matter to compel domestic consumers to install better equipment. Possible solution lies in two lines of effort: (1) education to improve firing methods and to install mechanical equipment wherever it can be afforded; and (2) placing upon the market a prepared coal which will burn without smoke at a cost that will attract the domestic consumer to its use.

There is no one universal choice of a smokeless fuel within the price range of the majority of domestic users. Coke is favored by some and it appears that its use is gaining headway. Up to the present, however, Illinois coals have not been extensively coked, but indications are that they will be increasingly made into coke. In view of the vast resources of coal in Illinois and the importance of knowing their coking possibilities, the State Geological Survey is carrying on investigations of their coke, gas, and by-product making properties, and plans to publish a report at an early date.

The present report, however, concerns the preliminary results of another line of study, namely the preparation of smokeless briquets made by impact without binder from partially volatilized Illinois coals. The discoveries made appear to be promising for providing the domestic consumer with another type of smokeless fuel at a cost that will allow it to enter the competitive market with other fuels.

---

[1] Blackwell, H. D., Chicago smoke survey shows need of education, better equipment: Coal Heat 27, March, p. 5 (1935).

COMPARISON OF PRESENT AND FORMERLY DESCRIBED BRIQUETS

The partially volatilized coal product used for making impacted smokeless briquets differs in composition, properties, and appearance from that of previously described products made from Illinois coals.[2] The present product retains a high volatile content (from about 25 to 30 per cent) as contrasted to other smokeless products of relatively low volatile content (usually less than 15 per cent); it retains its granular form as contrasted to other smokeless products possessing a cellular coke-like texture; and it has a high specific gravity, sinking in water, as contrasted to other semi-coked products which have a specific gravity from 0.5 to 0.7. The specific gravity of the smokeless briquet is over 1.2. Because of their relatively greater density, smokeless briquets burn with less rapidity than porous coke.

PROTECTION OF PROCESS BY PATENT

The process of making smokeless briquets without binder has been protected in the interest of the people of Illinois by U. S. Patent No. 2,021,020. Also, it is planned to apply for patent to protect the discovery that a non-coke smokeless fuel, retaining a relatively high volatile matter content, may be processed from Illinois coals by the preferential distillation of the low-temperature fractions of the volatile matter.

ACKNOWLEDGMENTS

Samples of Illinois coal for processing and for smoke index tests were furnished through the courtesy of various Illinois coal mining companies.

The impact machine of the Department of Theoretical and Applied Mechanics of the University of Illinois was used through the courtesy of Professor M. L. Enger, Dean of the College of Engineering.

J. M. Nash and H. C. Roberts, assistants in the Physics Division, and for a brief time, Dr. F. W. Cooke, carried on the laboratory tests and assisted in construction of apparatus. Chemical analyses were made in the analytical laboratory of the Survey under the direction of Dr. O. W. Rees, Associate Chemist. Assistance in preparation of the report was furnished by Dr. G. H. Cady, Head of the Coal Division of the Geological Resource Section, and by Dr. M. M. Leighton, Chief.

---

[2] The reader is referred to the following publications by S. W. Parr: Anthracizing of bituminous coal, Illinois State Geol. Survey Bull. No. 4, p. 196, 1906; The modification of Illinois coal by low temperature distillation, Univ. of Illinois Eng. Exp. Sta. Bull. No. 24, 1908; The coking of coal at low temperatures, Univ. of Illinois Eng. Exp. Sta. Bull. No. 60, 1912; The coking of coal at low temperatures with special reference to the properties and composition of the product, Univ. of Illinois Eng. Exp. Sta. Bull. No. 79, 1915; and Low temperature carbonization of coal, Second International Conference on Bituminous Coal, p. 54, Vol. I, 1928.

CHAPTER III—SMOKELESS BRIQUETS

INTRODUCTION

The use of fine sizes of coal in the production of a briquet by impact and without use of an artificial binder has been shown to be possible.[1] By a partial volatilization of the coal before impacting, smokeless briquets can be made by the same general technique.

DESIRABILITY OF SMOKELESS COAL BRIQUETS

Smokeless coal, prepared by partial volatilization, would be in an unmarketable form for many uses unless subsequently briquetted. The smokeless impact briquets possess several advantages over many other solid fuels. They are preferable to briquets made from carbonized coal with the aid of a binder because such briquets are usually smoky. Their ignition and maintenance temperatures are believed to be lower than those of most natural smokeless coals because of their remaining higher volatile matter content.

In the tests made in an open grate they burned without swelling and disintegration, presumably on account of the prior removal of low-temperature volatile fractions. Due to their dense structure, they burned from their surface inwardly, similar to a hard coal rather than a soft coal.

They are clean to handle as compared with raw bituminous coal and possess the same advantages as any other briquetted coal in respect to uniformity of size and structure.

METHODS OF PRODUCTION OF SMOKELESS BRIQUETS

There are at least four methods by which essentially smokeless briquets may be made, namely: (1) subsequent carbonization of coal briquets, formed with binder; (2) subsequent carbonization of coal briquets formed without binder; (3) briquetting of carbonized coal using a binder (which adds to the smokiness of the resultant briquet to an extent depending upon the smokiness of the binder); and (4) the process herein described which consists of briquetting without binder, by impact, processed smokeless coal fines.

In regard to (1), several processes have been devised for subsequent carbonization of coal briquets containing binder, but none of these has assumed commercial importance in the United States.

---

[1] Piersol, R. J., Briquetting Illinois coals without a binder by impact. Second Report: Illinois State Geol. Survey Report of Investigations No. 37, 1935.

In regard to (2), a summary of the various methods of producing briquets without binder for subsequent carbonization was presented in a previous report.[2]

At an early stage in the present investigation, an attempt was made to partially carbonize briquets made from natural coal by impact without binder. Preliminary results showed that ordinary briquets could be transformed into smokeless briquets with but slight swelling and cracking, but involving a considerable loss in mechanical strength.

In the meantime, it was discovered that coal prevolatilized to a smokeless degree could be impacted without binder directly into a smokeless briquet possessing a mechanical strength greater than that of a briquet made direct from the same natural coal by impact without binder. Therefore, the former line of attack was dropped in favor of this method.

In regard to (3), various carbonized fuels, such as coke breeze, petroleum coke, and charcoal, and also anthracite fines are briquetted with binder. An excellent summary of the literature on briquetting carbonized fuel with binder is given by Stillman,[3] and a review of the more recent literature is given by the author in the two reports previously cited.

BRIQUETTING WITHOUT BINDER, BY IMPACT, OF PROCESSED SMOKELESS COAL FINES

The fourth general method of producing smokeless briquets is the process herein described, which consists of briquetting by impact, without binder, processed bituminous coal fines from which the smoke-producing content has been removed. So far as is known, there is no previous literature on this line of investigation.

COALS USED IN THE INVESTIGATION

For determining the relationship between the volatile matter of raw coals and their smokiness a series of six banded bituminous coals were used of rank varying from high volatile bituminous *C* to low volatile coal. The high volatile bituminous *C* rank was represented by coal from Will County, Illinois, with a rank index of 120[4] and by coal from Washington County with a rank index of 126[5]; the high volatile bituminous *B* rank was represented by coal from Franklin County with a rank index of 131[6]; medium volatile bituminous coal was represented by coal from the Jewell bed, Wyoming County, West Virginia, with dry mineral-free volatile matter content of 23.3 per cent; and low volatile bituminous coal by two coals from the Beckley bed, one from Beckley County and the other from Raleigh County, West Virginia, with dry mineral-matter-free and volatile matter content of 18.1 and 16.4 per cent respectively. Coals of intermediate rank—high volatile bituminous *A* were not used in the investigation. These coals were also used as a basis of comparison of the smokiness of partially devolatilized coals in the form of briquets and of natural smokeless coal.

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[2] Piersol, R. J., Briquetting Illinois coals without a binder by compression and by impact: Illinois State Geol. Survey Report of Investigations No. 31, 1933, pp. 14-15.

[3] Stillman, A. L., Briquetting applied to carbonized coal, "Briquetting" pp. 336-357, The Chemical Publishing Company (1923).

[4] State Geol. Survey Bulletin 62, p. 222, Mine Index No. 359.

[5] Idem. p. 279. Mine Index 86.

[6] Idem. p. 314, average for Franklin County.

Table 1 shows the proximate analyses of the Illinois coals used for making smokeless briquets and of the Illinois and West Virginia coals used for smoke index tests of natural coals. Analyses herein reported for the Illinois coals were made in the Analytical Laboratory of the Geological Survey and those for the West Virginia coals were obtained from Black's Directory, Fourth Edition, 1935.

The detailed results of the effect of the degree of volatilization on the smoke index and the influence of the percentage of naturally occurring volatile matter on the smoke index of the coal are given in Part II.

EQUIPMENT USED IN THE PARTIAL VOLATILIZATION OF ILLINOIS COALS

The laboratory equipment for processing coal by removal of low-temperature volatile fractions consists of a rotary oven in which the coal is partially volatilized and an exhaust hood for removing the escaping gases. The equipment for the quantitative measurement of the smoke content of both natural and processed coals consists of a smoke index apparatus, to be described.

Rotary oven.—The rotary oven used for the partial volatilization of coal in this investigation is a modification of that[7] used previously for the preheating of coal to be briquetted.

The present rotary oven consists of a heating cell, constructed from a 5¾-inch length of 3⅛-inch pipe, so mounted as to rotate within a stationary 6-inch length of 3½-inch pipe, around which is wound the heating element. For the insertion of a thermocouple, a ¼-inch copper tube, with its inner end closed, extends to the center of the cell through the rear end which is removable by means of a spanner wrench. The front end of the cell is closed by a permanent steel inset, through which there extends outwardly a 3-inch length of ¼-inch steel tubing that serves both as an outlet for the escaping gas and as a means for rotating the heating cell. The rear end of the stationary pipe is closed by a transite inset with an opening through which the thermocouple passes; the front end is open.

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[7] Piersol, R. J., Briquetting Illinois coals without a binder by impact. Second Report: Illinois State Geol. Survey Report of Investigations No. 37, Fig. 1, p. 21, 1935.

TABLE 1.—PROXIMATE ANALYSES OF COALS USED FOR SMOKE INDEX AND BRIQUETTING TESTS

Analysis No.	Date of analysis	Location	Bed	Condition (*a*)	Moisture	Ash	Volatile matter	Fixed carbon	Total sulfur	B. t. u.
		Samples used for smoke index of volatilized coals								
C-738	1934	Will Co.	2	2	....	5.3	43.9	50.8	3.4	13299
C-740	1934	Franklin Co.	6	2	....	7.1	35.9	57.0	1.1	13246
		Samples used for smoke index of natural coals								
C-418	1933	Will Co. (B) (*c*)	2	1	9.1	4.7	43.5	42.7	2.9	12369
				2	....	5.2	47.8	47.0	3.2	13605
				3	....	....	....	....	....	14517
(*d*)	1934	Washington Co. (*c*)	6	1	8.5	7.2	41.5	42.8	4.2	11913
				2	....	7.8	45.4	46.8	4.6	13030
				3	....	....	....	....	....	14448
(*e*)	1934	Franklin Co. (B)	6	1	8.7	10.0	33.8	47.5	2.0	11640
				2	....	10.9	37.0	52.1	2.1	12746
				3	....	....	....	....	....	14513
(*f*)	1934	Raleigh Co., W. Virginia (A)	Beckley	1	0.7	5.2	16.2	77.9	0.7	15120
				2	....	5.2	16.3	78.5	0.7	15227
				3	....	....	....	....	....	17160
(*g*)	1921	Beckley Co., W. Virginia (B)	Beckley	1	....	....	....	....	....	....
				2	....	5.0	17.7	77.3	0.6	14850
				3	....	....	....	....	....	15720
(*h*)	1935	Wyoming Co., W. Virginia (C)	Jewell	1	1.4	4.0	22.5	72.1	0.6	14750
				2	....	4.1	22.8	73.1	0.6	14957
				3	....	....	....	....	....	15670

(*a*) 1—as received basis; 2—moisture-free basis; 3—unit coal basis (dry mineral matter free)
(*b*) Heated to 250°C. before analysis. Reported on dry basis. Moisture less than one per cent on as received basis.
(*c*) Partly air dried.
(*d*) Calculated from mine average moisture- and ash-free values, Bull. 62, p. 186, Mine No. 86, average of three samples given.
(*e*) Calculated from mine average moisture- and ash-free values, Bull. 62, pp. 140-141, Mine No. 136, average of nine samples given.
(*f*) Bed average obtained from Mine No. 189, p. 289, Black's Directory, Fourth Edition, 1935.
(*g*) Bed average obtained from Mine No. 99, p. 283, Black's Directory, Fourth Edition, 1935.
(*h*) Bed average obtained from Mine No. 19, p. 277, Black's Directory, Fourth Edition, 1935.

Exhaust system.—The exhaust system consists of a 10 × 12-inch hood, supported over the front end of the rotary oven, and connected through a flexible tubing to a vacuum cleaner unit that discharges outside of the building through 2-inch piping.

EQUIPMENT USED FOR BRIQUETTING

The laboratory equipment used in making smokeless briquets consists of a Turner impact machine and a briquetting die. A tumbling barrel is used to determine the mechanical strength of the briquets.

Impact apparatus.—The Turner impact machine[8] consists of two vertical standards serving as guides for drop hammers of various weights, from 50 to 500 pounds, which are raised to the desired height by an electromagnet and dropped by breaking the electric circuit.

Briquetting die.—The impact dies used in making smokeless briquets are all of the same design as the compaction die used previously.[9] The spool-shaped die is made of cold rolled steel, No. 2320 S. A. E., 3.5 per cent nickel, the wearing parts of which are case-hardened. The outer sleeve of the spool is wound with a heating coil, 20 feet of No. 19 resistance wire, which is covered with an asbestos jacket. Rheostat control permits maintenance of the temperature of the die at any desired value up to 400°C. At the higher temperatures hardened clarite steel, quenched at 600°C., is used for die parts. The temperature of the die is measured by a thermocouple inserted into an opening in the lower part of the outer sleeve. The cylindrical briquet, 1½-inch diameter, is impacted within the space confined by an inner sleeve, a fixed bottom plunger, and a movable top plunger. The impact blow from the hammer is transmitted to this movable plunger through an auxiliary plunger extending above the top of the die.

EQUIPMENT USED IN DETERMINING MECHANICAL STRENGTH

Tumbling barrel.—The same tumbling barrel is used as previously described in Report of Investigations No. 31. It consists of an 8-inch length of an 8-inch inside diameter pipe with ¼-inch wall, the ends of which are closed by round steel plates, ¼-inch thick, one being removable for the insertion and removal of briquets. Three equally spaced 1-inch angle irons that run the length of the barrel act as baffles. The barrel is half filled with flint pebbles, with a total weight of 5000 grams and an approximate weight of 25 grams each.

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[8] Illustrated in Fig. 8, p. 31, Report of Investigations No. 31.
[9] Illustrated in Fig. 2, p. 18, Report of Investigations No. 31.

SMOKE INDEX APPARATUS

The smoke index equipment[10] used in this investigation consists of, (a) an electric muffle furnace, so equipped that a specified temperature and rate of air supply can be maintained; (b) a light-absorption tube through which all smoke is drawn; and (c) a smoke density system composed of a source of a beam of constant intensity which passes through the absorption tube, a photo-electric cell at the other end of the tube, and a galvanometer.

EXPERIMENTAL PROCEDURE IN MAKING SMOKELESS BRIQUETS

Preparation of coal samples for partial volatilization.—Since the size of material which gave most uniform volatilization results and was best adapted to briquetting was minus 4-mesh, all samples were reduced to this size upon receipt at the laboratory, being stored in air-tight receptacles to avoid excessive moisture loss. Immediately before use, in either volatilization or briquetting tests, the samples needed were obtained by quartering from the storage sample.

In order to obtain approximately the same size briquets, either 45-gram or 50-gram samples were used, depending on the moisture content of the coal.

Removal of low-temperature volatile matter.—In making volatilization tests the steps in the procedure were as follows: (1) the temperature of the rotary oven (measured by the thermocouple inserted in the copper tube) was raised to a predetermined value by use of an appropriate equilibrium heating current, which maintained a constant temperature throughout the test; (2) the heating cell was removed from the stationary pipe, its removable end opened, the weighed quantity of coal inserted, the end closed, and the loaded cell replaced, the entire operation requiring about 30 seconds; (3) the exhaust motor was started; (4) throughout the test, the heating cell was hand-rotated rapidly at 1-minute intervals to prevent sticking of the coal and to insure uniform distribution of temperature and degree of volatilization; (5) at the end of the predetermined period of volatilization, the temperature of the coal was recorded; (6) the heating cell was removed; (7) the coal was cooled to a pre-determined temperature; and then (8) the coal was transferred from the heating cell to the impact die, previously heated to the same pre-determined temperature.

Briquetting technique.—In the formation of smokeless briquets, the partially volatilized coal at various specified temperatures was transferred to the impact die previously heated to various selected temperatures. The top surface of the coal in the die was leveled, and the movable plunger was lightly pressed down so that it entered the cylinder for a short distance. The loaded die was clamped to the foundation directly beneath the impact hammer as described in the preliminary report already cited. The auxiliary plunger supporting a 1-inch steel plate 4 × 4 inches, was inserted on top of the movable plunger. The 500-pound hammer was dropped from various selected heights, care being taken to avoid a second impact on the rebound. The die was unclamped, opened, and the briquet was pressed out of the inner cylinder by means of a hydraulic press at pressures between 500 and 1000 pounds. With downward taper (approximately 0.020-inch increase of diameter per inch) of the inside wall of the portion of the die surrounding the finished briquet, only a slight pressure is necessary to cause the briquet to fall out of the die. Each briquet was weighed immediately in order to determine its combined moisture and volatile loss.

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[10] Piersol, R. J., Smoke index: a quantitative measurement of smoke. This report, pp. 49-51.

PROCEDURE IN MAKING TUMBLING TESTS

The tumbling barrel was rotated at 40 r.p.m. for 2 minutes in the determination of the tumbling loss for smokeless briquets, all conditions being identical to those previously reported for the determination of the tumbling loss of ordinary briquets. Also, the weight and size of a smokeless briquet made from a 50-gram sample of coal is approximately the same as that of an ordinary briquet made from a 45-gram sample of coal. Therefore, the tumbling losses of the two kinds of briquets are directly comparable.

PROCEDURE IN DETERMINING SMOKE INDICES

Preparation of samples.—In preparing samples for smoke index determination seven or eight 1-cm. cubes were cut from each briquet and three or four cubes from the center of a lump of each coal tested. The latter were cut immediately before testing to avoid air-drying loss as much as possible. They were all approximately the same weight, as determined by actual weighing.

Smoke index method.—A complete statement of the smoke index method is given in Part II. Briefly, the procedure for the determination was as follows: The cube of coal, on a nickel dish set on a movable tray, was placed in the center of the furnace. The furnace was maintained at a temperature of 600°C. and with an air supply of 4 cubic feet per minute. Galvanometer readings were taken at 5-second intervals, starting at the instant the sample was placed in the furnace and continuing throughout the period of smoke liberation.

The total smoke was calculated as the product of the average amount of smoke produced and the time required for its liberation. The smoke index (smoke per gram) was obtained by dividing this total smoke content by the initial weight of the sample.

EXPERIMENTAL RESULTS

TUMBLING TESTS

The results concern (1) the effect of the amount of volatile matter removed on the mechanical strength of the resultant briquets, and (2) the effect of the briquetting temperature on the mechanical strength of the briquets.

Effect of amount of volatile matter removed on mechanical strength of briquets.—The influence of degree of volatilization on the mechanical strength of briquets was ascertained for Will County and Franklin County coals.

Will County coal was volatilized at temperatures of 373°, 448°, 460°, 466°, 475°, 485°, 494°, and 505°C. for ten minutes, then cooled to 300°C. and impacted by a 4½-foot drop of the 500-pound hammer.

It is shown in Table 2 (Fig. 1) that the volatile matter in briquets made from volatilized Will County coal may be as low as 31.9 per cent without detrimentally affecting their strength. Such a briquet has a smoke index value less than one-third of that of West Virginia coals, as is shown on pages 28 and 106.

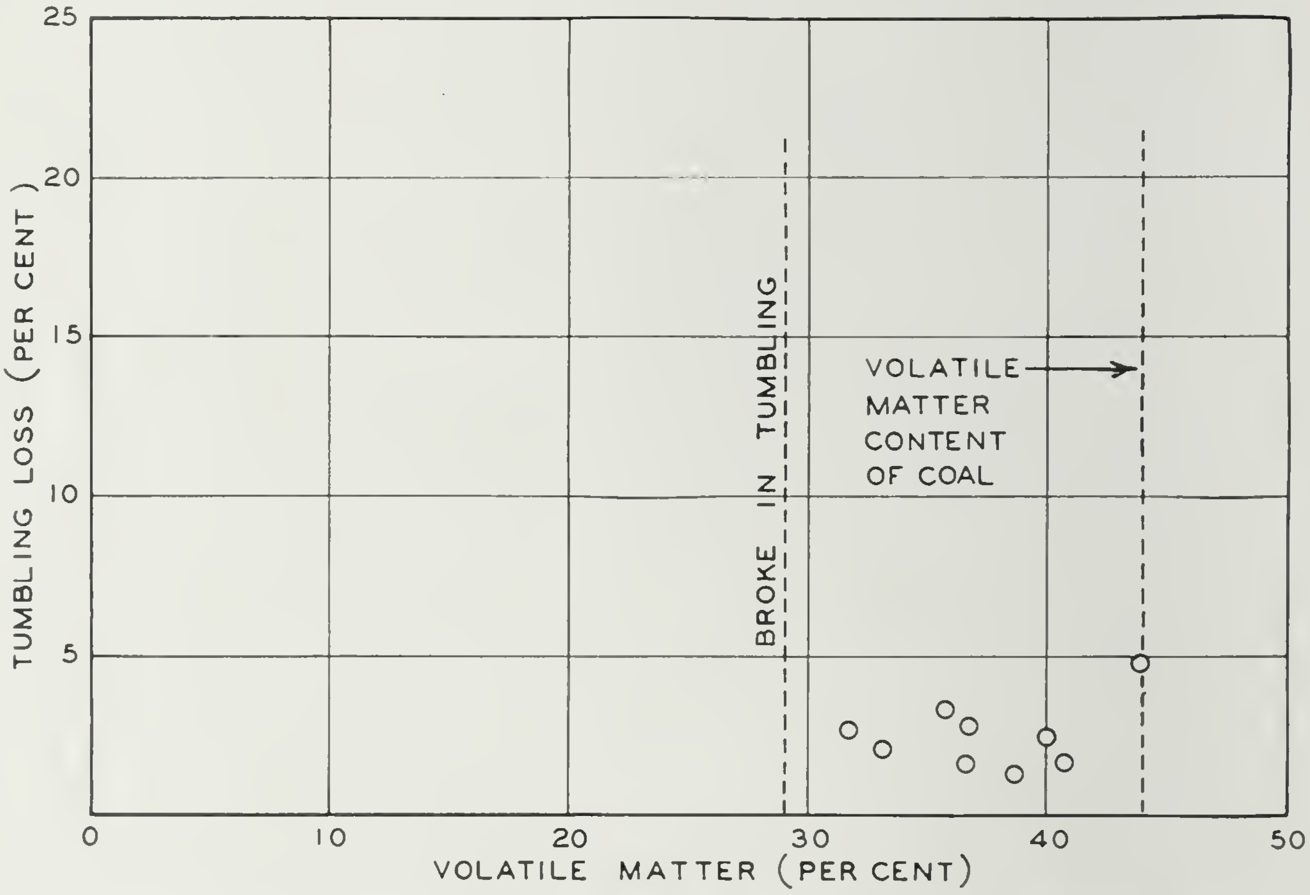

Fig. 1.—Mechanical Strength of Will County Briquets as Affected by Volatile Matter Content.

Franklin County coal was volatilized at temperatures of 425°, 440°, 455°, 470°, and 482°C. for ten minutes, then cooled to 300°C. and impacted by a 4½-foot drop of the 500-pound hammer.

Table 2.—Mechanical Strength of Will County Briquets as Affected by Volatile Matter

(Data for Fig. 1)

Volatilization coal temperature °C.	Oven temperature °C.	Volatile matter (per cent)	Tumbling loss (*a*) (per cent)
373	425	43.7	4.8
448	490	40.5	1.8
460	500	39.8	2.7
466	510	38.5	1.3
475	520	36.8	2.9
475	525	36.4	1.8
485	530	35.7	3.4
494	540	33.0	2.2
505	550	31.9	2.8

(*a*) Percentage loss in weight after 2 minutes tumbling.

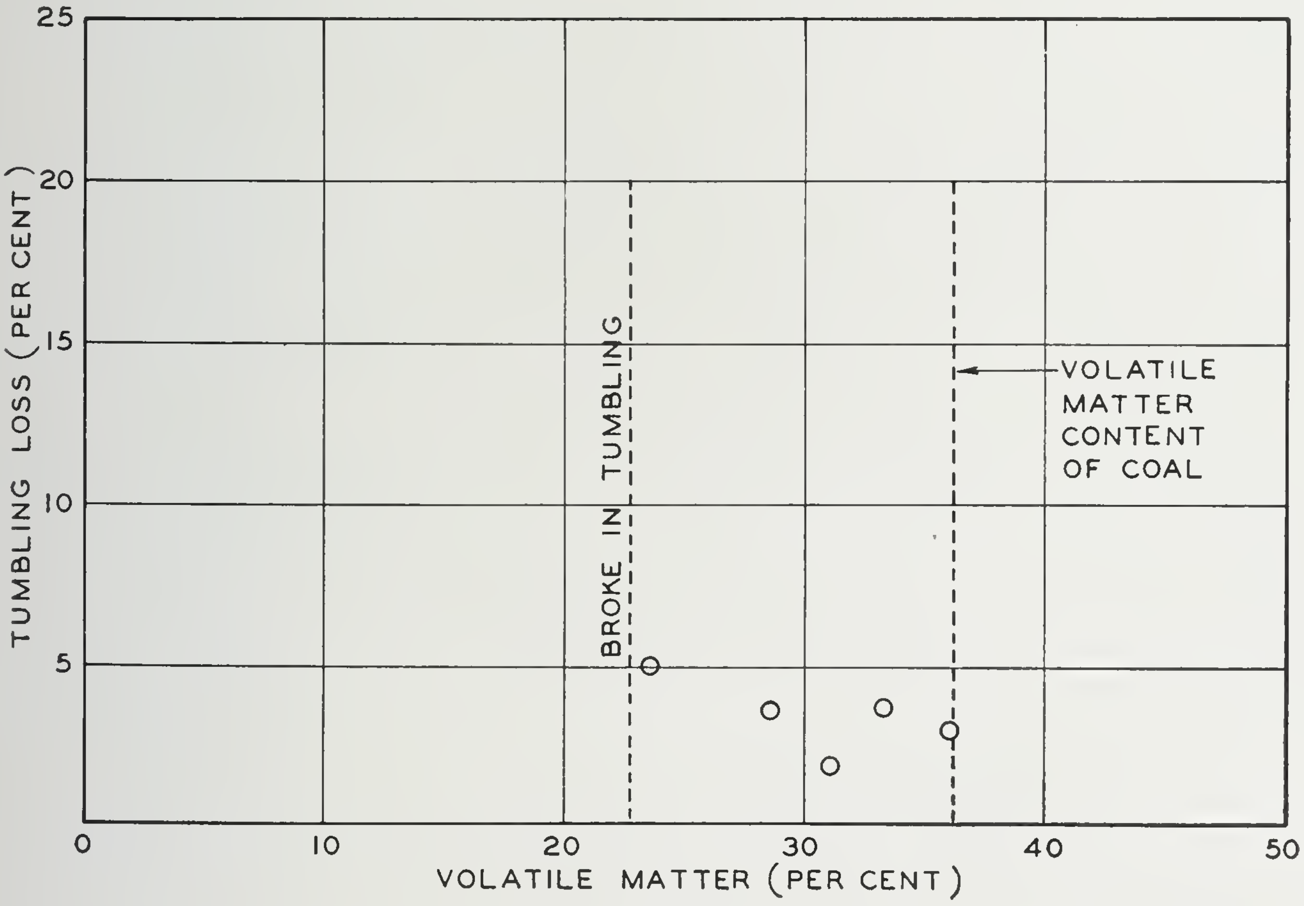

Fig. 2.—Mechanical Strength of Franklin County Briquets as Affected by Volatile Matter Content.

The results of tumbling loss tests on a similar series of briquets made from Franklin County coal are shown in Table 3 (Fig. 2). The strength of these briquets is satisfactory for volatile matter content as low as 23.6 per cent. Such a briquet has a smoke index value less than one-seventh of that of West Virginia coals, as shown on pages 28 and 106.

TABLE 3.—MECHANICAL STRENGTH OF FRANKLIN COUNTY BRIQUETS AS AFFECTED BY VOLATILE MATTER

(DATA FOR FIG. 2)

Volatilization coal temperature °C.	Oven temperature °C.	Volatile matter (per cent)	Tumbling loss (*a*) (per cent)
250	275	35.9	2.8
425	460	33.0	3.6
440	480	30.9	1.8
455	500	28.6	3.5
470	520	23.6	4.9
482	540	22.6	disintegrated

(*a*) Percentage loss in weight after 2 minutes tumbling.

Effect of briquetting temperature on mechanical strength of Will County smokeless briquets.—In this series of tests all conditions were maintained constant except the briquetting temperature (that of the impact die and that to which the coal was cooled). Briquets were made from Will County coal volatilized to 33.1 per cent volatile matter content at a temperature of 460°C. (coal temperature) maintained for five minutes, the shorter period and lower temperature being due to continuous rotation of the oven. Then the coal was cooled to the briquetting temperatures of 250°, 300°, 350°, and 400°C., and then impacted by a 4½-foot drop of the 500-pound hammer.

TABLE 4.—MECHANICAL STRENGTH OF WILL COUNTY SMOKELESS BRIQUETS CONTAINING 33.1 PER CENT VOLATILE MATTER, IMPACTED BY A 4½-FOOT DROP OF THE 500-POUND HAMMER, FROM COAL VOLATILIZED AT 460 °C. (COAL TEMPERATURE) FOR 5 MINUTES, AS AFFECTED BY BRIQUETTING TEMPERATURE

(DATA FOR FIG. 3)

Briquetting temperature (°C.) (*a*)	Tumbling loss (*b*) (per cent)	
	Individual	Average
250	4.8	
250	5.1	5.0
300	1.9	
300	3.5	2.7
350	1.9	
350	1.1	1.5
400	1.3	
400	1.6	1.2
400	0.8	

(*a*) The briquetting temperature is that of the impact die and, also, that to which the coal is cooled subsequent to volatilization to 33.1 per cent volatile matter.
(*b*) Percentage loss in weight after 2 minutes tumbling.

Table 4 (Fig. 3) indicates that the mechanical strength of smokeless briquets increases with increasing briquetting temperature.

Although a briquetting temperature of 400°C. results in a slightly stronger briquet than that obtained at 300°C., nevertheless the latter temperature was selected for use in other tests since it did not require an impact die made of clarite steel.

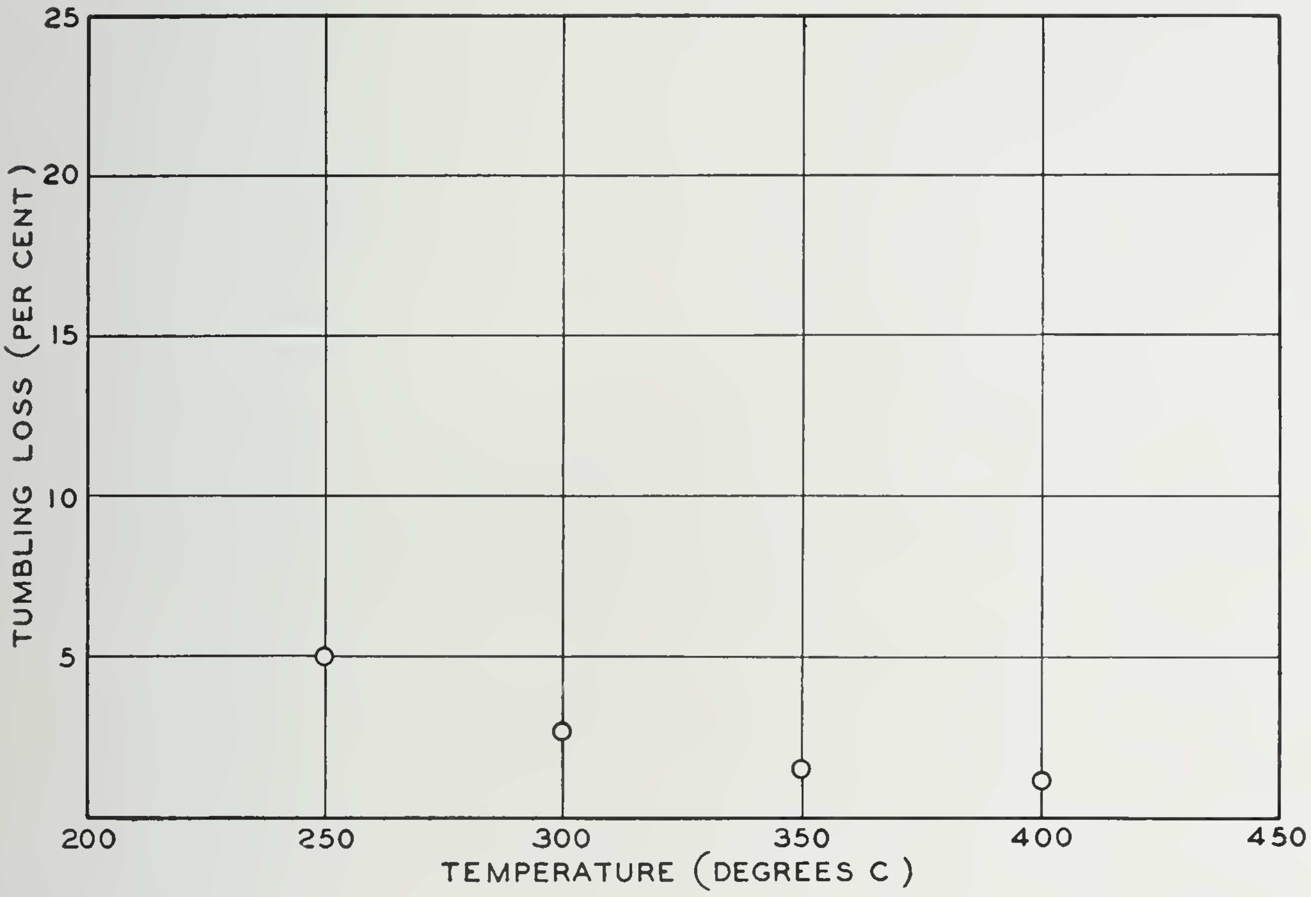

Fig. 3.—Effect of Briquetting Temperature on Mechanical Strength of Will County Smokeless Briquets.

No tests were made to determine whether the die should be held at the same temperature to which the coal has been cooled, because in the rapid commercial production of briquets the die would tend to maintain the same temperature as the coal.

TIME-TEMPERATURE CURVE FOR 15 PER CENT VOLATILE MATTER LOSS

There is a wide range of time (8.5 minutes to 40 minutes) possible for volatilization to produce the required reduction in volatile matter, the length of time decreasing with increased temperature of volatilization as shown in Table 5 (Fig. 4), but in commercial practice, in order to maintain the optimum volatile matter content, it would be essential to adjust the temperature to the period of volatilization, or vice versa. This is discussed more fully in Part II of this report, pages 107-110.

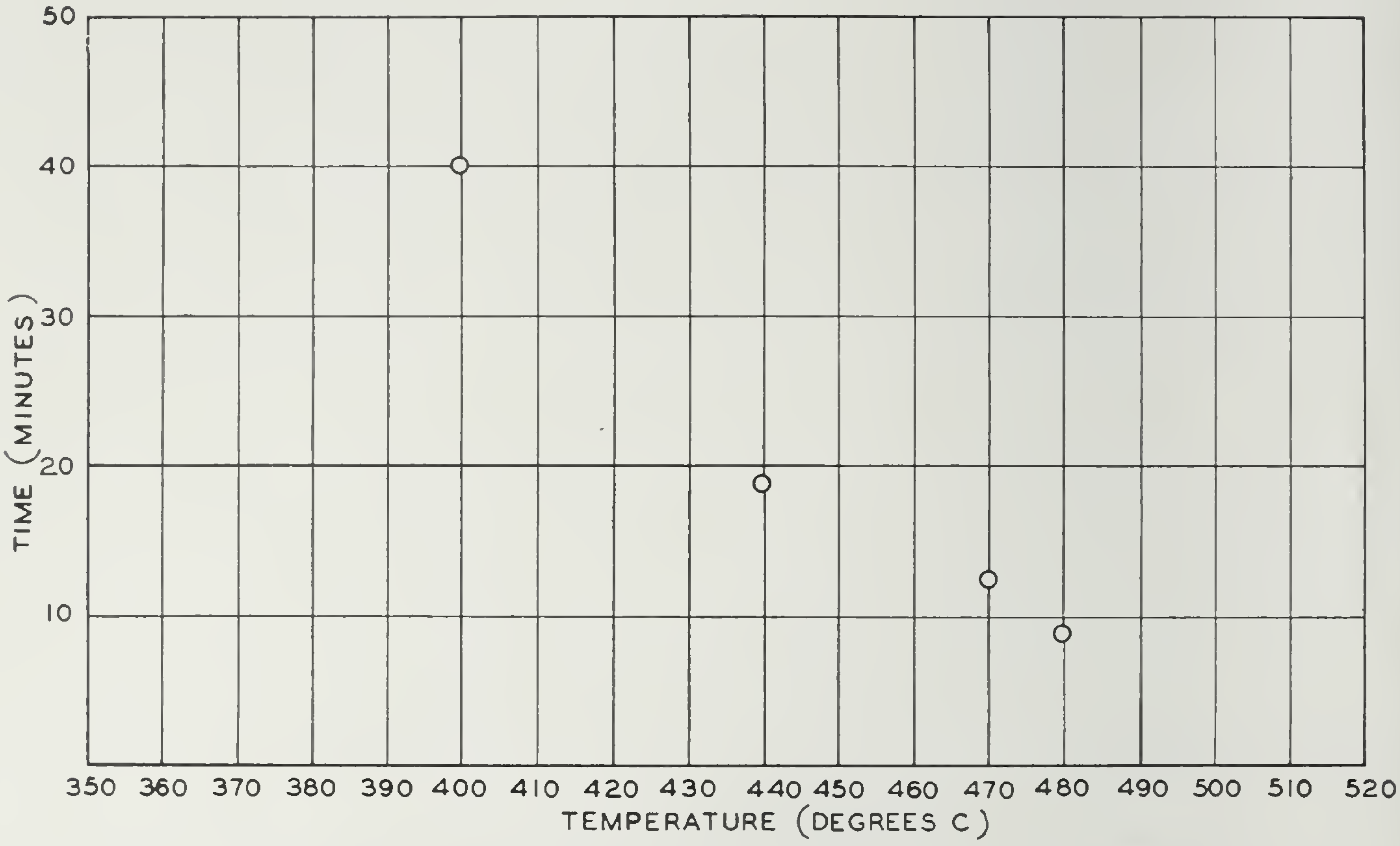

Fig. 4.—Time-Temperature Curve For 15 Per Cent Volatile Matter Loss For Will County Coal.

Table 5.—Time-Temperature Data for Optimum Volatile Matter Loss of Will County Coal

(Data for Fig. 4)

Volatilization period (minutes)	Volatilization temperature of the coal (°C.)	Oven temperature (°C.)	Weight loss (per cent)	Volatile matter (*a*) (per cent)
0			0.0	43.9
90	390	400	10.6	37.3
75	390	400	10.6	37.3
75	390	390	5.9	40.4
40	400	420	15.3 (*b*)	33.8
40	400	405	9.4	38.1
35	400	415	11.8	36.4
30	400	410	11.8	36.4
20	445	500	17.7	31.8
18.5	440	450	15.3 (*b*)	33.8
13	475	500	18.8	30.9
12	470	500	15.9 (*b*)	33.3
11	460	500	12.9	35.6
9	495	550	18.8	30.9
8.5	480	550	15.9 (*b*)	33.3

(*a*) Percentage volatile matter calculated from experimental weight loss, "dry basis."

(*b*) Optimum volatile matter loss is selected at a value of about 16 per cent (weight loss).

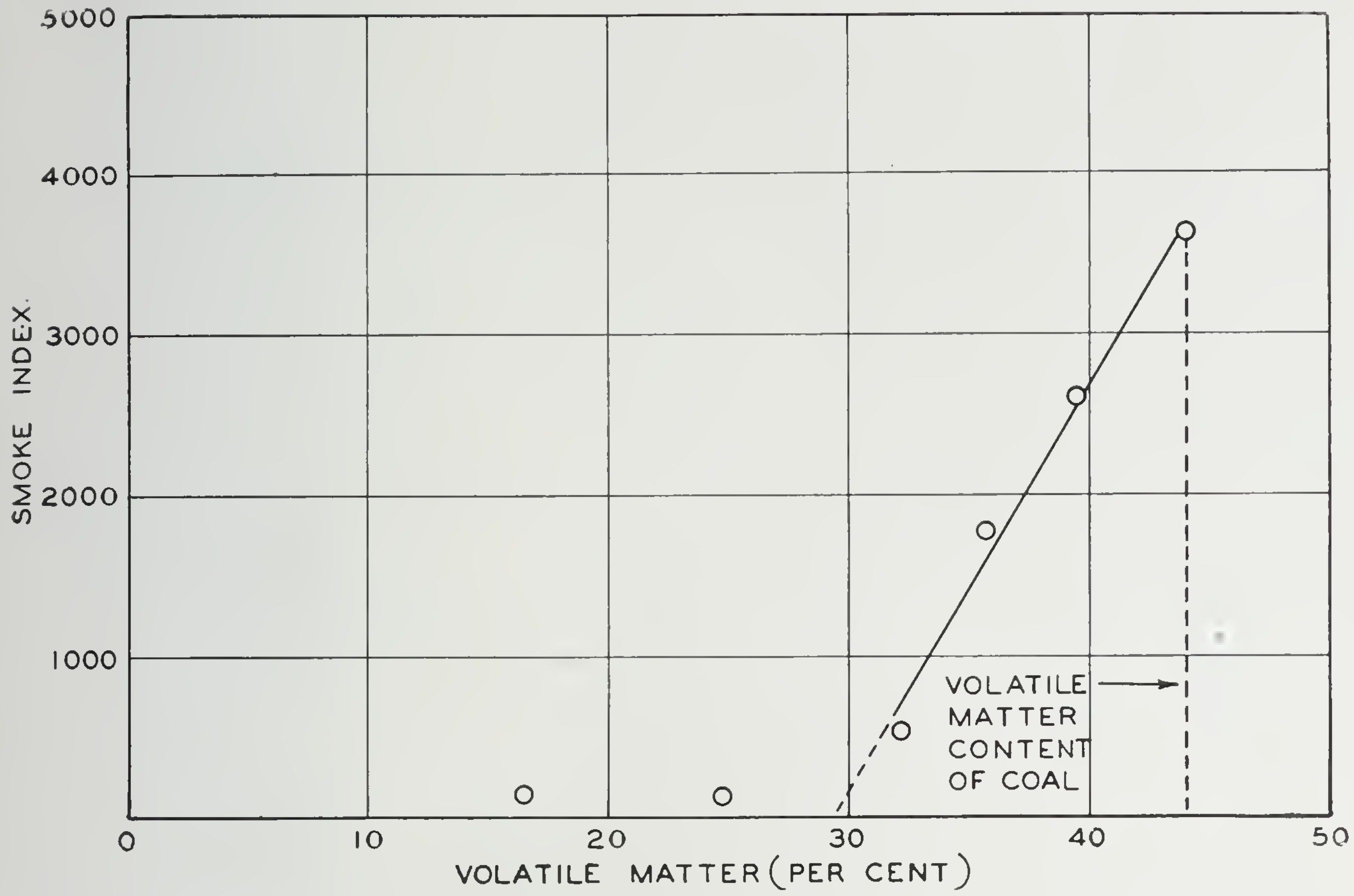

Fig. 5.—Effect of the Amount of Volatilization on the Smoke Index of Will County Briquets.

Table 6.—Summary of Data Showing the Effect of Amount of Volatilization on Smoke Index of Will County Briquets

(Data for Fig. 5)

Volatilization coal temperature (°C.)	250°	477°	485°	505°	515°	535°
Weight loss (per cent)	0.0	7.6	12.7	17.6	25.9	32.9
Volatile matter (*a*) (per cent)	43.9	39.3	35.8	31.9	24.3	16.4
Test No.	*Smoke indices*					
1	3230	3540 (*b*)	1640	263	245	159
2	3670	1880	1590	777	98	96
3	4090	3360	1470	550	127	140
4	3800	3400	1880	273	64	188
5	3890	2030	1980	871	183	....
6	3460	3040	1820	526	66	....
7	3360	1730	1920	324	104	....
8	....	1910	1820	475	238	....
Average	3640	2610	1770	507	141	146

(*a*) Percentage volatile matter calculated from determined weight loss.

(*b*) Individual samples showed variation far beyond that to be expected from the heterogeneous structure of the coal, possibly due to greater volatilization of the smaller grains of coal.

SMOKE INDEX DETERMINATIONS

Table 6 (Fig. 5) is a summary table which shows the influence of the remaining percentage of volatile matter on the smoke index of briquets impacted from processed Will County coal. A 10-minute volatilization, at a coal temperature of 505°C., results in 17.6 per cent loss in volatile matter (also weight loss on a dry basis); thereby reducing the volatile matter content from 43.9 per cent to 31.9 per cent and reducing the smoke index from an average of about 3600 for the dry coal to an average of about 500 for the briquet impacted from the processed coal. This value of smoke index is less than one-third of that of a so-called West Virginia smokeless coal, the average smoke index value of such a coal, with a volatile content of 16.2 per cent, being 1770 (Table 25, West Virginia A coal, Part II of this report).

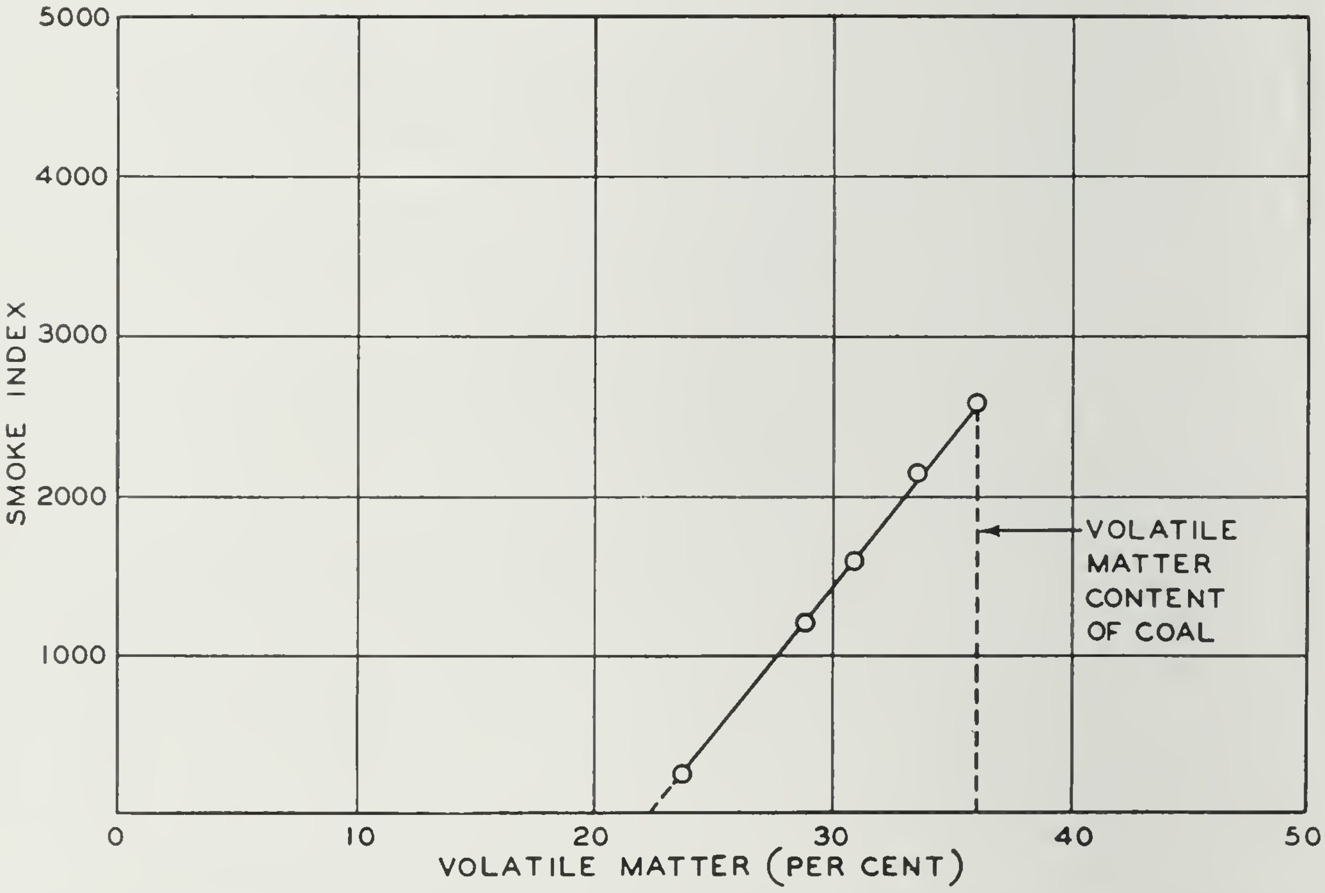

Fig. 6.—Effect of the Amount of Volatilization on the Smoke Index of Franklin County Briquets.

Table 7 (Fig. 6) is a similar summary table for the smoke index of briquets impacted from processed Franklin County coal. A 10-minute volatilization, at a coal temperature of 495°C., results in 16.1 per cent loss in volatile matter; thereby reducing the volatile matter content (dry basis) from 35.9 per cent to 23.6 per cent and reducing the smoke index from an average of about 2600 to an average of about 250, the latter value being less than one-seventh of that of the West Virginia smokeless coal. Reference may be made to Part II of this report for the detailed results on the smoke index of smokeless briquets.

Table 7.—Effect of Amount of Volatilization on Smoke Index of Franklin County Briquets

(Data for Fig. 6)

Volatilization temperature (°C.)	250	450	465	480	495
Weight loss	0.0	4.3	7.3	10.3	16.1
Volatile matter (*a*)	35.9	33.1	30.9	28.5	23.6
Test No.	*Smoke indices*				
a	2480	2120	1140	956	175
b	2400	1940	1830	1580	86
c	2480	2490	1800	934	176
d	2670	2090	1910	1310	414
e	2710	2300	1650	937	47
f	2710	2580	1290	1610	449
g	2820	1620	1590	1220	170
h	2440	....	....	....	479
Average	2590	2160	1600	1220	250

(*a*) Percentage volatile matter calculated from experimental weight loss.

ESTIMATED ENERGY COSTS

Although actual power consumption can be determined only by commercial scale production, nevertheless, certain estimates may be made of the cost of the mechanical and heat energy required in making smokeless briquets.

Approximately the same impact energy is required as that for making ordinary impacted briquets. It was estimated in Report of Investigations No. 37 that 50 pounds of coal (so burned as to produce one horsepower-hour for each two pounds of coal) would be sufficient to supply the mechanical energy to make one ton of briquets.

On the above combustion efficiency, about 100 pounds of coal are necessary to preheat the coal for one ton of ordinary briquets, but for smokeless briquets approximately 50 per cent more heat is required, so that this method would require about 150 pounds of coal per ton of briquets.

An approximate calculation of the heat necessary to raise dry coal to a given temperature may be based on the specific heat of coal. In order to drive off the desired 15 per cent volatile matter the coal must be preheated up to a temperature of about 900°F. (482°C.). If the coal has an average temperature of 70°F. before preheating, this requires an increase of about 830°F. Since coal possesses a specific heat of approximately 0.3. it thus requires 249 B.t.u. to preheat one pound of dry coal. If coal is used as a source of fuel to volatilize the coal and if it is so burned as to deliver 5000

B.t.u. per pound of coal, then 100 pounds of coal is needed to preheat one ton of dry coal or 120 pounds of coal per ton of smokeless briquets. If the coal is not dry, an additional quantity of fuel is necessary to drive off the moisture, the quantity depending upon the percentage of moisture present. Thus in general about 150 pounds of coal are required for preheating one ton of smokeless briquets.

The total energy consumption is, therefore, equivalent to about 200 pounds of coal per ton of briquets.

The 15 per cent volatile matter liberated in processing coal to a smokeless product is readily combustible. Future tests will be made to determine the volume produced per ton of coal processed and its B.t.u. per cubic foot. If desired, this liberated gas may be burned to furnish a part, or perhaps all, of the fuel required to operate the briquetting unit.

The shrinkage of coal in producing a ton of smokeless briquets is equal to the percentage moisture plus 15 per cent, which is the amount of volatile matter removed. Therefore, for a particular Illinois coal containing 10 per cent moisture, the total shrinkage in making smokeless briquets would be 25 per cent of the coal used.

FUTURE INVESTIGATIONS

The present preliminary report describes an exploratory laboratory investigation in which it is shown beyond reasonable doubt that Illinois coal may be processed into a smokeless product by the removal of the very low-temperature fractions of its volatile matter and, second, that this product may be impacted without binder into strong smokeless briquets. This is being followed by further investigations which include:

(1) Operating range, including temperature and time of volatilization, impact die temperature, and impact pressure.

(2) Properties of smokeless briquets, including mechanical strength, smoke index, weathering and burning characteristics.

(3) Effect of the rank of coal and the coal components (banded ingredients), sulfur, and ash.

(4) Systematic tests on a variety of Illinois coals.

(5) Further detailed study of the processing of Illinois coal fines into a smokeless product for domestic consumption without subsequent briquetting.

II. SMOKE INDEX: A QUANTITATIVE MEASUREMENT OF SMOKE

R. J. PIERSOL

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SMOKE INDEX: A QUANTITATIVE MEASUREMENT OF SMOKE

CHAPTER I—INTRODUCTION

PURPOSE OF INVESTIGATION

IT HAS BEEN discovered that Illinois slack coal may be briquetted by impact without the use of an artificial binder,[1] and that excellent smokeless fuel briquets may be impacted without binder from Illinois slack coal which has been partially volatilized.[2] In the pursuit of the research on smokeless briquets, it became desirable to develop a quantitative measurement of smoke. Such a method of measurement permits the accurate determination of the smokiness of both naturally occurring coals of various volatile matter content and of briquets impacted from coal fines processed to various volatile matter content by the method herein described.

The Encyclopedia Britannica describes smoke as follows:

"Smoke is a general term applied to the visible exhalations from burning materials.

"Nearly all fuels consist essentially of carbon, hydrogen, oxygen and nitrogen, in various proportions and variously combined. In addition, they usually contain a little sulfur, while in solid fuels varying amounts of incombustible mineral ash are also incorporated. If complete combustion were always attainable, no fuel would emit smoke, the final products in such an ideal case being limited to carbon dioxide, water vapor, and free nitrogen, all quite innocuous gases, and invisible unless the water vapor condenses to a cloud of steam. There would, however, if sulfur were present, also be produced small quantities of sulfur dioxide gas, which, also invisible, has a pungent smell, and in contact with air and moisture tends rapidly to be converted into a corrosive acid; while the mineral constituents would remain unburned in the form of ash.

"To achieve such finality it is necessary only that a fuel should be brought into contact with enough air for full oxidation while maintained at a temperature sufficiently high for combustion to take place. These conditions, although apparently simple, are by no means easy to realize, and in practice some proportion of a fuel always eludes complete combustion. The unburned products vary widely in amount and in composition according to the nature of a fuel and the manner of its use, being in some circumstances inappreciable, in others very large. They are moreover not necessarily in the form of smoke, since with insufficient air carbonaceous materials may emit gaseous intermediate products such as carbon monoxide and unsaturated hydrocarbons; but whether or not smoke is produced, incomplete combustion is always indicative of thermal loss.

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[1] Piersol, R. J., Briquetting Illinois coals without a binder by compression and by impact: Illinois State Geol. Survey Report of Investigations No. 31, 1933.

[2] Part I of this report, pp. 7-30.

"Thorough admixture with air is relatively easy to secure in the case of gaseous fuels, which in properly constructed and properly adjusted burners produce neither smoke nor other unburned products in appreciable quantity. An inadequate air supply, however, or the chilling or smothering of the flames, may result in the evolution of unburned gaseous products, including carbon monoxide and oxides of nitrogen, both highly poisonous; or in extreme cases may even cause the deposition of soot.

"Owing to the relatively high density of solid fuels, the problem of bringing them into contact with sufficient air for complete oxidation is greatly intensified, and, even with an air supply far in excess of that theoretically required, perfect combustion cannot in practice be counted upon.

"With bituminous coals, smoke production to a greater or lesser degree, according to the circumstances, is practically unavoidable; for such coals are subject to decomposition at temperatures below the ignition point, with the evolution of combustible gases and condensable tarry vapors. These are of so complex a character, and under the action of heat are subject to such complicated chemical changes, that although the more readily ignitible constituents may burst into spasmodic flames, others almost inevitably escape unburned. Coal smoke consists of such unconsumed distillation products, in association with carbon and tarry matter condensed by premature chilling of flame, together with dust and ash entrained by the upward rush of hot air and gases from the grate. Some of this settles on the walls of the flue as soot; the remainder is carried out through the chimney into the atmosphere with the excess air and gaseous products of combution, both burned and unburned."

SCOPE OF INVESTIGATION

The present investigation included, first, a survey of previous methods used for smoke determination; second, development of a laboratory method and equipment for determining the total amount of smoke emitted during the combustion of a small sample of fuel; third, standardization of equipment under most suitable conditions for testing; fourth, methods of calculating the smokiness of a sample of fuel in terms of a factor, referred to as the smoke index; fifth, the determination of the smoke index of naturally occurring coals of various volatile matter contents; and sixth, the determination of the smoke index of briquets impacted from Illinois coal fines processed to various volatile matter contents.

The method described in this report measures the total quantity of smoke produced by the combustion under standard conditions of a small weighed sample of fuel; previous methods have determined only the gross effect of smoke produced in commercial furnaces.

The present equipment is so designed that the total smoke liberated, under controlled conditions, in combustion of a small sample of fuel of known weight, passes through a tube for light absorption where the smoke density is measured at regular time intervals by means of a photo-electric cell. The galvanometer deflections produced by the photo-electric cell are used to calculate the smoke index of the sample.

In order for such a method to be of service it is necessary that results be reproducible within the desired degree of accuracy. Also, it is desirable that the equipment be so standardized that comparative results may be obtained in other laboratories. As is well known, coal does not possess a simple chemical composition, and it is therefore difficult, if not impossible, to use coal as a standard for calibration of smoke measurement equipment in various laboratories. Thus it was necessary to seek a material which might serve as a suitable standard for this purpose.

Further, it is desirable to use an expression which signifies the total amount of smoke liberated in burning a unit quantity of fuel under standard conditions of testing. For this, the term smoke index is used. It is arrived at by multiplying the average percentage absorption of light by the time (in seconds) of smoke emission of one gram of fuel. As shown later, the value of the smoke index may be calculated algebraically or determined graphically.

SUMMARY OF FINDINGS

The equipment developed for the measurement of smoke index consists of an electric muffle furnace in which the sample of fuel may be burned at a certain temperature and with a specified supply of air. All the smoke produced is drawn through an absorption tube at a constant rate of flow and the smoke density is measured by its absorption of a beam of light, of known intensity, passing lengthwise through the tube. The amount of light thus absorbed is determined by a Weston Photronic cell and a galvanometer, the readings being taken at regular intervals.

Smoke equipment of this type is not described in the literature, so far as known, and therefore it is impossible to calibrate it against any previous standard. Thus it was desirable to devise some method by which it, or any similar equipment built by another laboratory, may be calibrated against a material having a constant smoke index for specified conditions of burning.

It is found that naphthalene, when burned at a furnace temperature of 90°C. (10°C. above its melting point) in a container of suitable size and shape, possesses a constant smoke index. Naphthalene is obtainable in pure form as moth balls. Thus any duplicate equipment for measuring smoke index of coal or other fuel may be calibrated by using naphthalene as a standard material.

The smoke index and the rate at which the smoke is emitted are influenced greatly by the conditions under which the fuel is burned. In order to find the most suitable temperature for measuring the smoke index of coal, the range from 600°C. to 1000°C. was investigated. Lower temperatures were not investigated since some bituminous coals have ignition temperatures approaching 600°C. The data obtained indicated that the most reproducible results are obtained at 600°C. Therefore this temperature was selected for use in all tests.

For the same reason, the influence of air supply on the smoke index was investigated. With an air flow less than 4 cubic feet per minute an excessive quantity of soot was deposited on the inner surfaces of the equipment. Data showed that reproducible results are obtained with an air supply of 4 cubic feet per minute.

Also a series of tests were made to determine the degree of reproducibility on as nearly identical samples of coal as were obtainable, these samples differing slightly, however, in weight. The time required for combustion indicated a high degree of uniformity of the samples. The results showed a maximum deviation from the average smoke index of 6.3 per cent and a mean deviation of 3.7 per cent.

The results of the investigation show that there appears to be a direct proportionality between the smoke index and the percentage of volatile matter in the Illinois and West Virginia coals investigated.

For the Illinois coal fines processed by the method herein described, there is also a linear relationship between the smoke index and the percentage of volatile matter in the partially volatilized product, although the decrease in the smoke index is far more rapid than the decrease in volatile matter. Thus a smokeless briquet may be prepared with a much higher volatile matter content than that of a naturally occurring smokeless coal.

ACKNOWLEDGMENTS

Mr. J. M. Nash, Physics Assistant of the Survey staff, carried out the larger part of the experimental work with assistance furnished by the Civil Works Administration as follows: Dr. F. W. Cooke, Physicist, Dr. J. J. Gibbons, Physicist, Dr. R. W. Tyler, Physicist, and Mr. P. G. Jones, Physics Assistant. Mr. H. C. Roberts, Physics Assistant of the staff, designed and constructed the equipment. Dr. C. F. Fryling, Chemist, Non-fuels Division of the Survey, suggested the use of naphthalene for standardization. Dr. O. W. Rees, Associate Chemist, Analytical Division, of the Survey, supervised the chemical analyses. The Peabody Coal Company furnished the sample of coal.

CHAPTER II—PREVIOUS METHODS OF SMOKE DETERMINATION

Previous methods of smoke determination have included smoke density measurements, analytical measurements, and smoke recorders. Also furnace air drafts have been controlled by photo-electric relays located in the smoke stacks.

SMOKE DENSITY MEASUREMENTS

One of the most common methods for measuring smokiness has been the determination of the optical density, or opacity, of the smoke as it issues from the stack. This method and all its modifications have the limitation of measuring only the density of a continuous column of smoke, thus failing to determine the total amount of smoke. However, this method gives valuable information in that the density of smoke liberated from various fuels, or the same fuel at various stages of combustion, may be compared.

By far the most widely used of these is the Ringelmann method[1] of determining the density of smoke. This method, which was devised by Professor Ringelmann, includes the use of a set of six comparison charts and a method of calculation. The six charts (Fig. 1) represent different degrees of gray, ranging from white to black. This method is described in the smoke abatement report of the Chicago Association of Commerce Committee of Investigation on Smoke Abatement as follows:

"Each chart is numbered for reference purposes, to-wit: No. 0—100% white; No. 1—80% white and 20% black; No. 2—60% white and 40% black; No. 3—40% white and 60% black; No. 4—20% white and 80% black; No. 5—100% black. The white on the chart is the clear background of the white paper on which the chart is made, and the black is in the form of lines in cross-section, for charts Nos. 1, 2, 3, and 4, the width of the lines being such that the proportional amount of black is shown. The whole surface of chart No. 5 is black.

"By placing the Ringelmann scale far enough from the eye, the cross-section lines on the four charts, Nos. 1, 2, 3, and 4, become diffused to the eye and appear as different shades of gray, while the white chart, No. 0, and the black chart, No. 5, appear unchanged in color.

"Comparative observations of smoke by the Ringelmann scale are made by placing the scale of six charts at the proper distance between the observer and the smoke to be observed, with a clear background for the smoke, and with no direct rays of the sun entering the eye of the observer. The color of the smoke emitted is then compared with the colors of the six charts—

---

[1] Smoke Report, Chicago Association of Commerce Committee of Investigation on Smoke Abatement and Electrification of Railway Terminals.

"The formula for computing the per cent of density of smoke is

$$\frac{\text{Smoke units x 20}}{\text{Stack minutes}} = \text{per cent of density}$$

"A 'stack minute' corresponds to the observation of one stack for one minute . . . A 'smoke unit' corresponds to the emission of No. 1 density of smoke for one minute, or its equivalent."

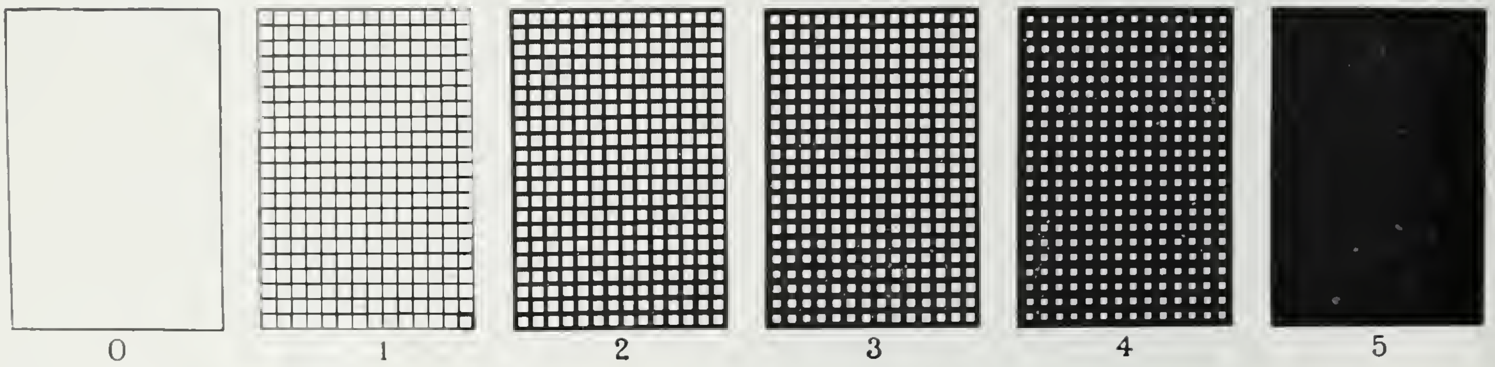

Fig. 1.—Ringelmann Chart of Smoke Densities.

This method evidently is limited to data on the gross amount of smoke passing through a stack. Therefore, it gives pertinent information as to optimum conditions of combustion, but, of necessity, it cannot give a quantitative measurement of the amount of smoke liberated per unit weight.

ANALYTICAL METHODS

A number of tests involving physical and chemical analyses have been developed. For determining the amount of solids in smoke, and extracting these solids for testing purposes, one method is as follows. The stack is fitted with a sampling tube into which part of the smoke is drawn, by means of a vacuum pump, through a fine paper filter which retains the solid part of the smoke. This solid part is weighed, screened to determine particle size, and then analyzed chemically. Solid particles larger than 20-mesh are classed as "coarse cinders," those between 20-mesh and 200-mesh, as "fine cinders," and those passing a 200-mesh screen are called "fuel dust." The solids are then analyzed to determine amounts of tarry matter, combustible matter, mineral matter or ash, and the sulfur compounds.

The gaseous part of the smoke, after having had the solids filtered out, may be analyzed to determine the amount of carbon dioxide, carbon monoxide, oxygen, nitrogen, sulfur compounds, etc., that may be present. Standard methods of gas analysis may be used for this. For convenience, the Hayes portable gas-analysis outfit is often used.

These chemical and physical tests give excellent and accurate information on the character, especially the destructive character and offensiveness, of the smoke produced. They require complicated and expensive apparatus with readings made by several operators at specified intervals and are consequently expensive. Also the results are similar to those obtained by smoke charts in that information is lacking as to the amount of smoke produced per pound of coal.

SMOKE RECORDERS

In many industrial districts adjacent to residential areas, ordinances are enforced which limit the density of smoke emitted by stacks. It is impossible to station an observer to take readings continuously at each stack, and to solve this problem, smoke recording devices have been constructed, such as the Hamler-Eddy smoke recorder (Fig. 2). In this instrument, a small amount of smoke is being constantly drawn from the stack, dried, and forced in a fine jet against the white paper surface of a revolving drum to which some

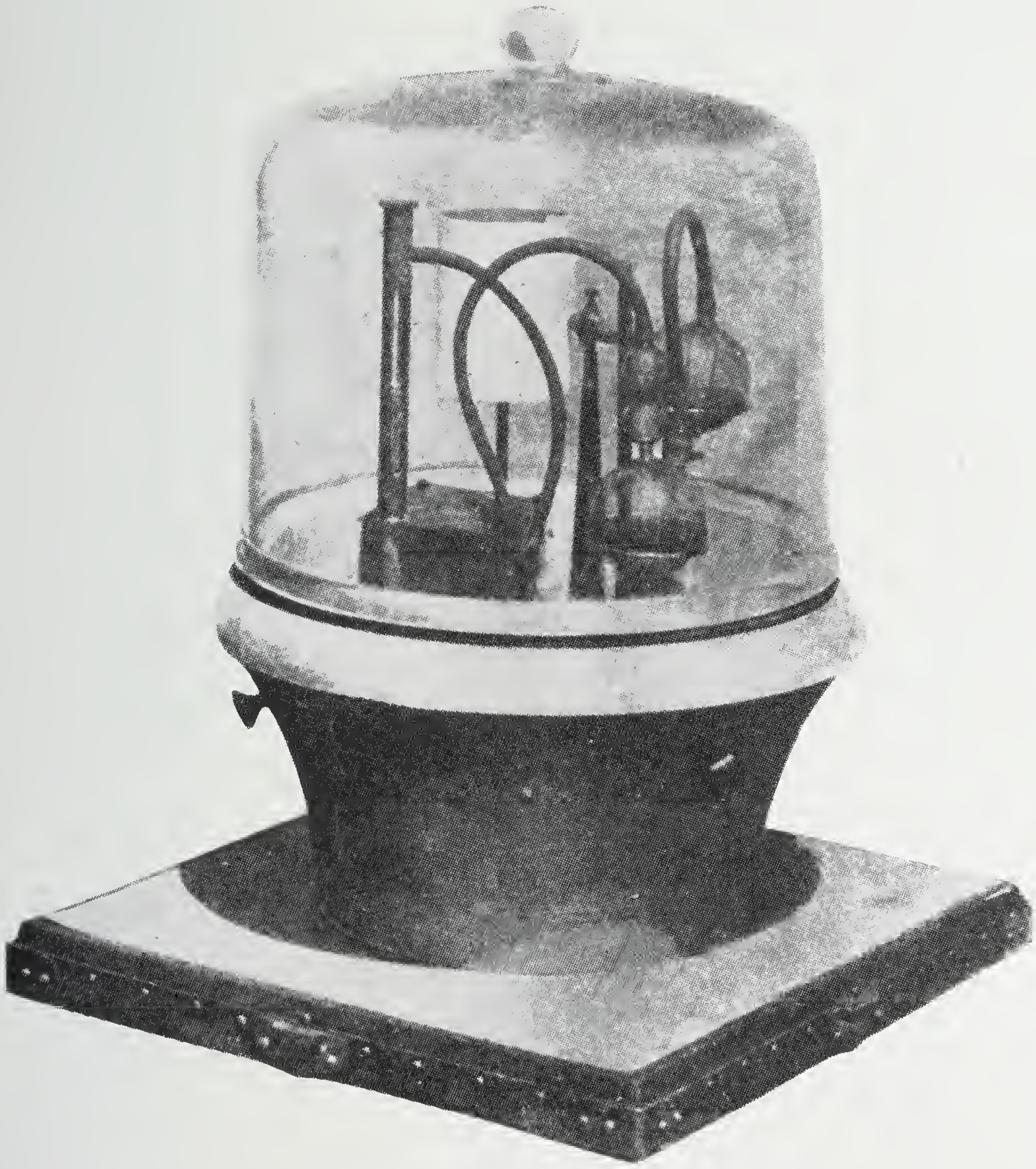

Fig. 2.—Hamler-Eddy Smoke Recorder.

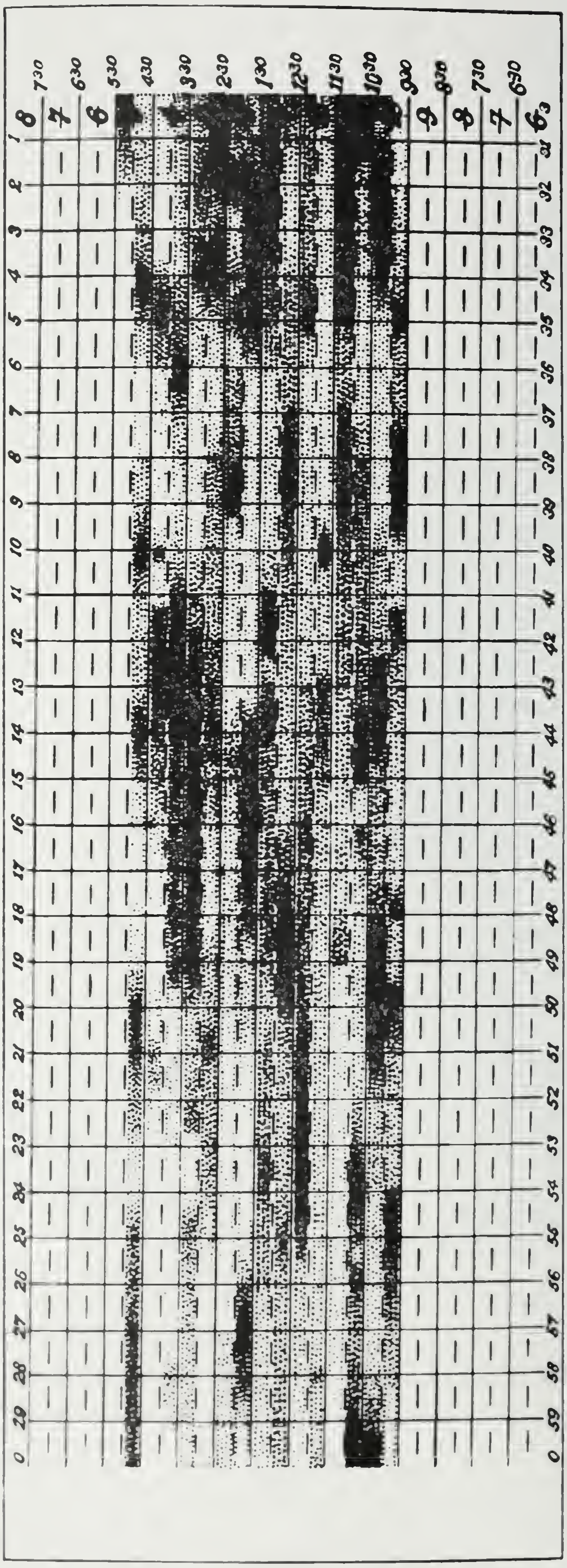

Fig. 3.—Chart Made by Hamler-Eddy Smoke Recorder.

Smoke Record Chart for Fourteen Hours

Read from right to left and from bottom upwards.
The figures on the right are the hour and half hours and those on the top and bottom are minutes of the hour.
The space below the *full line* is for the first half of the hour and that above the line is for the last half of the hour.

of the solids in the smoke adhere, giving a line of variable density, its density being proportional to the opacity of the smoke.

A more recent type of smoke recorder involves the use of the photo-electric cell set in the stack to determine continuously the density of the smoke. With the advent of the smoke abatement movement, a number of such devices have been installed in commercial plants for stack regulation. These instruments are all of the same general type although they differ somewhat in detail. A lamp giving a constant intensity of illumination is set inside, in the wall, or outside the stack, and its beam is directed across the stack, through the path of the smoke, to a photo-electric cell near the opposite wall of the stack. All or a definite fractional part of the smoke passing through the stack is allowed to obscure the beam of light, the density fluctuations of the smoke thereby causing corresponding fluctuations in the current generated by the photo-electric cell. The output of the cell may be amplified and the fluctuations recorded on a moving drum thus giving a continuous record of the smoke density. Or the cell may be connected to a sensitive relay which will automatically sound a warning signal when the smoke density exceeds the specified value.

All of the methods referred to above are intended for measurement of the density of smoke ejected into the atmosphere by a smoke stack. None of them gives a quantitative measurement of the amount of smoke given off by a given quantity of fuel while it is being burned to ash. Therefore, these methods are of little value in determining the inherent smokiness of a fuel, under a given set of conditions.

CHAPTER III—DESCRIPTION OF THE SMOKE INDEX METHOD

The smoke index method is a quantitative test which may be performed on any sample of fuel of any convenient weight. However, the present equipment has been developed for a sample of approximately one gram. The possibility of using a small sample has its advantages. For instance, tests may be made on one coal ingredient only, such as clarain; or tests may be made to determine the effect of size and shape of small particles (or to determine the effect of texture of a lump sample on the smoke produced, small lump samples may be used). In this study, the samples used were all cut to the same size and shape on a carborundum saw, their weights being slightly variable.

In direct contrast to all known previously used methods of measuring smokiness, the smoke index method measures the total amount of smoke produced. Every particle of smoke passes through the smoke absorption tube, requiring an appreciable time for its passage. The use of the smoke index method eliminates two defects of the previously used methods: i.e., the necessity for the by-passing of a small fraction of the total smoke through the apparatus; and the irregularities in smoke emission due to the periodic addition of fresh coal under ordinary firing conditions.

Since all the smoke passes through the absorption tube in the smoke index equipment, it is subject to measurement at every stage of burning, from before the time of ignition to complete ashing, if desired. The excessively large amounts of smoke liberated in the initial stages of burning are manifested, not being masked as they would be if other fuel in advanced stages of combustion were present at the same time. In fact, observed data are plotted so that they show clearly the relation of smoke produced to the stages of combustion.

The sample to be treated is placed in a muffle furnace, where conditions of temperature and air supply may be accurately controlled. The heat capacity of the furnace is sufficiently large that the heat which the small sample gives off while burning does not raise the temperature of the furnace appreciably. The present furnace weighs about 30 pounds, being constructed of materials which have an average of about 0.2 specific heat. Thus the heat capacity of the furnace is equivalent to that of 6 pounds of water. The calorific value of bituminous coal is usually less than 15,000 B.t.u. Therefore the combustion of a one-gram sample of coal liberates not more than 33 B.t.u.

which would raise the temperature of the furnace about 5.5°F. or 3.0°C. The sample is thus exposed to almost constant furnace temperature (within 3.0°C.) throughout all stages of combustion.

The smoke, as it issues from the burning sample, is drawn through the absorption tube. A beam of light is constantly passing axially along this absorption tube, striking the light-sensitive photo-electric cell which is connected to a galvanometer. When no smoke is present to obscure the light beam, the galvanometer shows a maximum deflection. As smoke enters, it partially intercepts the light falling on the photo-electric cell, and the amount of obscurity, or the smoke density, may be calculated from the change in the galvanometer reading. That is, the amount by which the galvanometer reading is decreased, in per cent, represents the proportion of light intercepted by the smoke in the absorption tube, in per cent. This in turn is in direct ratio to the amount of smoke present. If these individual smoke-density percentages, taken at regular intervals, are averaged, the result is the average per cent smoke density produced during the entire period of combustion. If this average is multiplied by the time required for combustion, in seconds, the total amount of smoke given off by that sample, in units of percentage smoke density and seconds time, is obtained. And if this total amount of smoke is divided by the weight of the sample used, the amount of smoke given off per gram of fuel, in terms of percentage smoke density and seconds time, is obtained. This value is called the smoke index.

The actual value of the smoke index for any particular sample may be obtained either by a graphical method or by a numerical calculation. Both methods are described herein.

CHAPTER IV—EQUIPMENT AND PROCEDURE

A detailed description of equipment and procedure is here included in order to permit other investigators to duplicate smoke index determinations.

EQUIPMENT

The essential equipment consists of an electric muffle furnace, a tube for light absorption by the smoke, a source of air supply, means for drawing the smoke through the absorption tube, a source of constant illumination, a photoelectric cell, and a galvanometer.

Furnace.—The electric muffle furnace (Fig. 4) constructed for use in the investigation consisted of a three-inch inside diameter alundum tube, A, 18 inches long, wound with two heating elements, B, of No. 19 "Chromel" wire and each having a resistance of 15 ohms. Each of the two elements had a separate controlling rheostat C, and an ammeter D, in series with it, so that

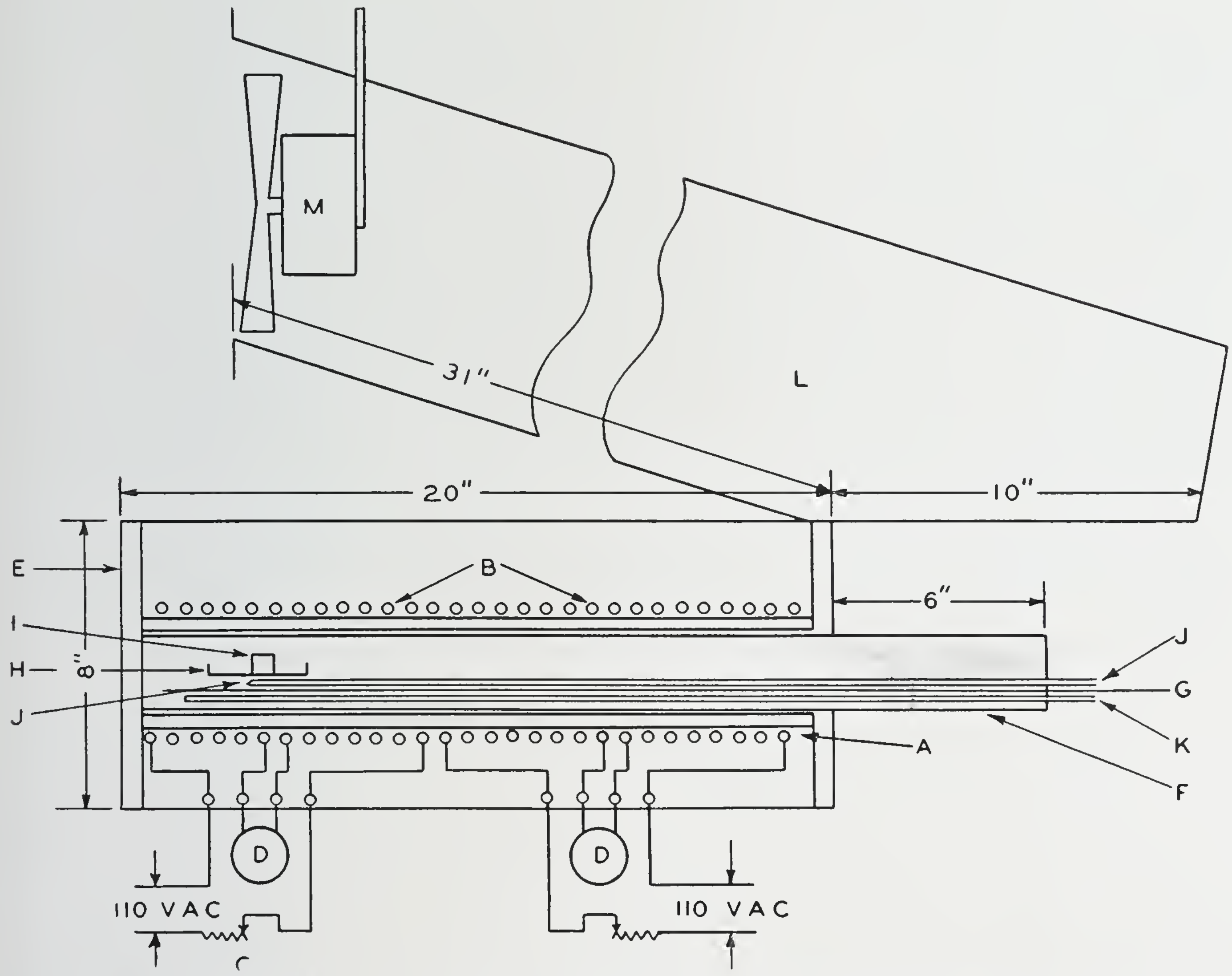

Fig. 4.—Diagram of Combustion Furnace. (Illinois State Geol. Survey Report of Investigations 37, Fig. 15, p. 69, 1935.)

the temperatures of the front and rear parts of the furnace could be controlled separately, if desired.

In the naphthalene standardization tests, the two heating elements were connected in series, in order to secure the low temperature of 90°C. In all the smoke index tests on coal, the two heating elements were connected in parallel, so as to make possible the higher furnace temperatures from 600°C. to 1000°C. In this case the same amount of current was passed through each coil, thereby insuring uniform temperature along the length of the furnace.

The alundum tube, with the heating coils, was given a coating of alundum cement about ¼-inch thick, fired, and then placed in a steel and transite case E, 8 inches square and 20 inches long, packed with "Sil-o-Cel". A steel tube, F, 2½ inches inside diameter and 26 inches long, was fitted into the alundum muffle to protect it and to increase the heat capacity of the furnace and thereby minimize small fluctuations in temperature.

A steel tray G, 1⅞ inches wide, ⅛-inch deep, and 30 inches long, was used to carry the container H, in which the sample I, was placed. The thermocouple J, was mounted in the tray with its junction directly under the sample container. The thermocouple leads extended to a potentiometer near the open end of the furnace. Air was introduced into the furnace through a small iron pipe K, leading to the back of the furnace, passing along the bottom of the muffle beneath the tray. The amount of air admitted to the furnace was measured by a calibrated differential manometer of orifice type.

Absorption tube.—The smoke given off by the burning sample is drawn from the mouth of the furnace A, through the absorption tube B, by a compressed air aspirator C (Fig. 5). This tube is 34 inches long and 1⅜ inches inside diameter, and its inner surfaces are blackened. At the end of the absorption tube nearest the furnace there is mounted a 15-watt, 110-volt A. C. inside-frosted incandescent bulb D, in the sleeve, in such a manner that the rounded surface of the bulb is 1 inch from a glass window F, closing the end of the absorption tube. On the other end of the absorption tube is a

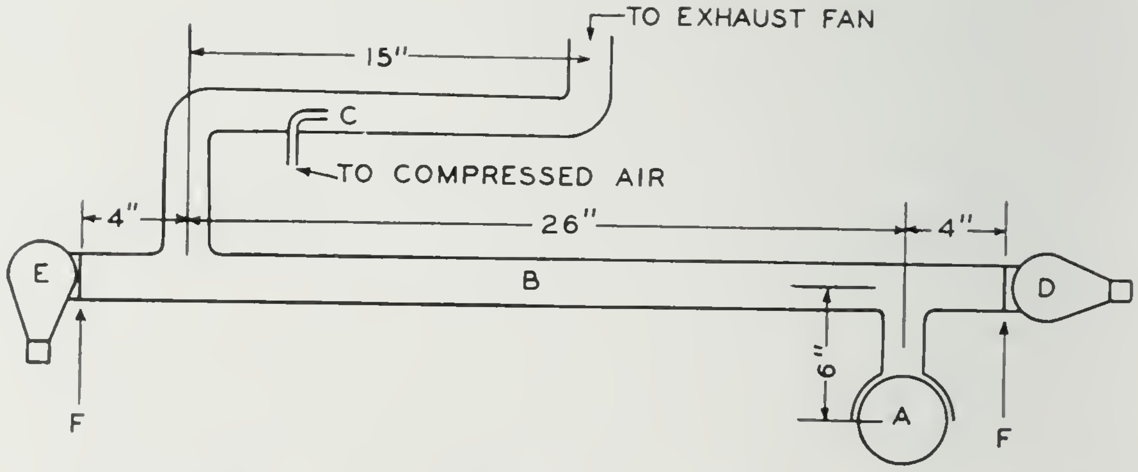

Fig. 5.—Photo-Electric Unit For Determination of Smoke Index.

similar sleeve in which the photo-electric cell E is mounted. As the smoke passes through the absorption tube the beam of light from the incandescent bulb, D, is partially obscured, the intensity of the transmitted light being measured by the photo-electric cell E. In the direction parallel to the axis of the tube and with no smoke present, the intensity of illumination on the photo-electric cell is 0.75 foot-candle. The ends of the tube are closed by the thin glass plates F, which are placed 4 inches from the inlet and outlet of the absorption tube. These windows may be cleaned as required, but, due to their position, remain fairly clean throughout one test. The assembled smoke index apparatus is shown in figure 6.

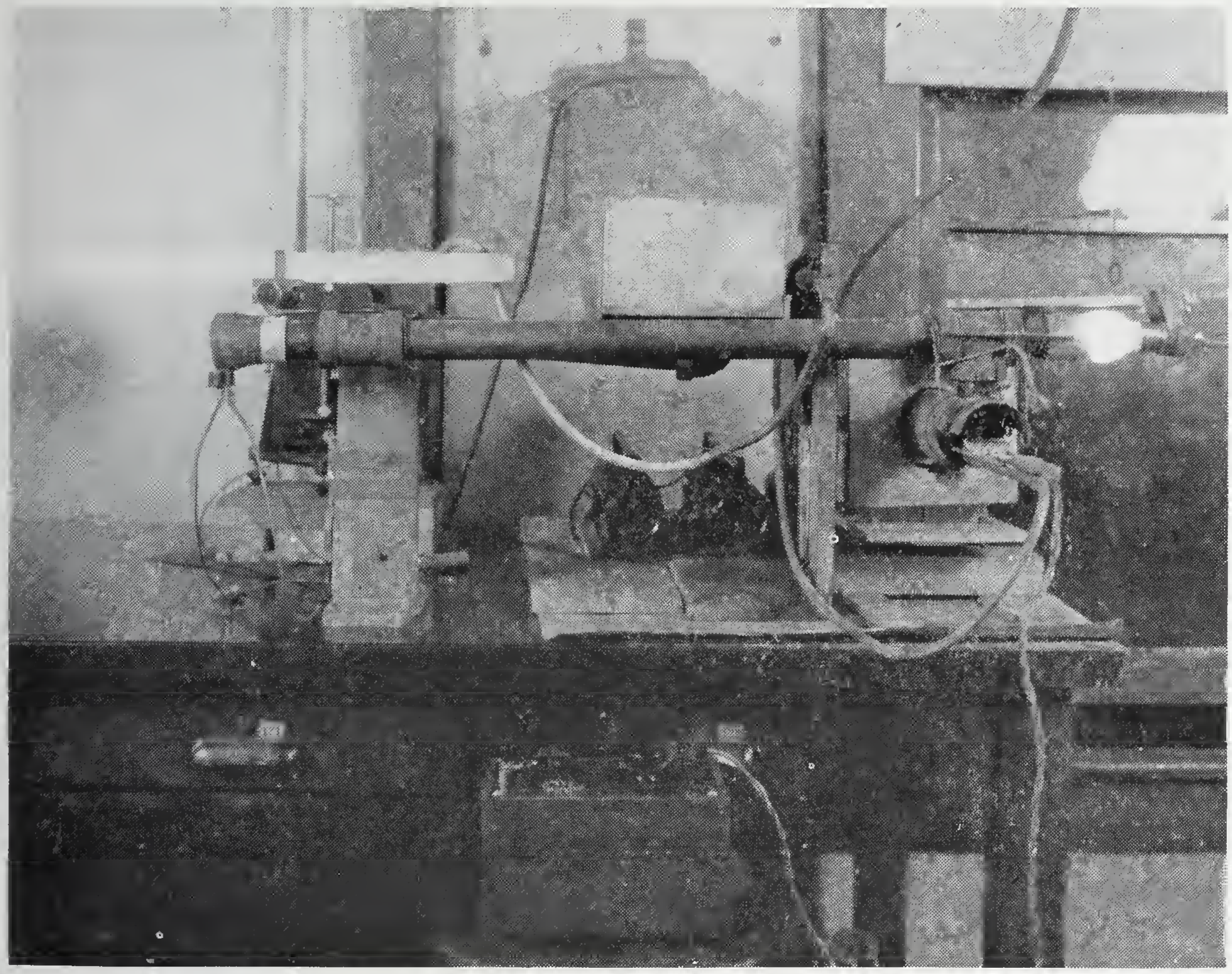

Fig. 6.—Assembled Smoke Index Apparatus.

The photo-electric cell used in this investigation was a Weston Photronic cell, Model 594. This cell, while not as sensitive as some of the alkali cells, is very durable. It was connected in series with a 3000 ohm resistance and a D'Arsonval type galvanometer (sensitivity = .00082 milli-amperes per millimeter at a distance of 1 meter).

PROCEDURE

Before using the smoke index equipment, it was necessary to calibrate the photo-electric cell, the incandescent lamp, and the differential manometer.

Calibration of apparatus.—The incandescent lamp, used as a light source, was an ordinary commercial 15-watt General Electric bulb. Its candlepower was determined, using a Bunsen photometric bench and a standard lamp. The candlepower of the incandescent bulb, in the direction along its axis from its rounded end, was found to be 20.4.

Table 1.—Calibration Data for Weston Photo-Electric Cell

(Data for Fig. 7)

Deflection (millimeters)	Intensity (foot-candles)
250	.729
234	.695
214	.632
193	.573
174	.528
157	.481
144	.445
130	.410
121	.381
114	.354
105	.331
99	.307
93	.289
87	.272
83	.256
79	.241
75	.227
72	.214
69	.204
67	.192
64	.183

A part of the surface of the incandescent lamp is obscured by the sleeve of the absorption tube when the lamp is in place in the apparatus. A determination of the light intensity at the photo-electric cell end of the absorption tube was made entirely separate from other calibrations. The galvanometer deflection from the photo-electric cell was 257 mm. with the lamp in place and supplied with an exact potential of 110 volts. The intensity of illumination on the photo-electric cell necessary to produce this deflection was found to be that given by the standard lamp, 46.97 candlepower, at a distance of 7.91 feet. The intensity of illumination was thus calculated, by dividing 46.97 by 7.91 squared, to be 0.75 foot-candle.

Also the photo-electric cell was calibrated, using the above standard lamp and varying the intensity of illumination on the light-sensitive surface of the photo-electric cell by placing the standard lamp at various distances. From the known candlepower of the standard lamp, it is possible to calculate the intensity of illumination (in foot-candles) which varies as the reciprocal of the square of the distance between the lamp and the surface of the photo-electric cell. The data for the calibration of the photo-electric cell are recorded in Table 1 and the corresponding calibration curve is plotted (Fig. 7).

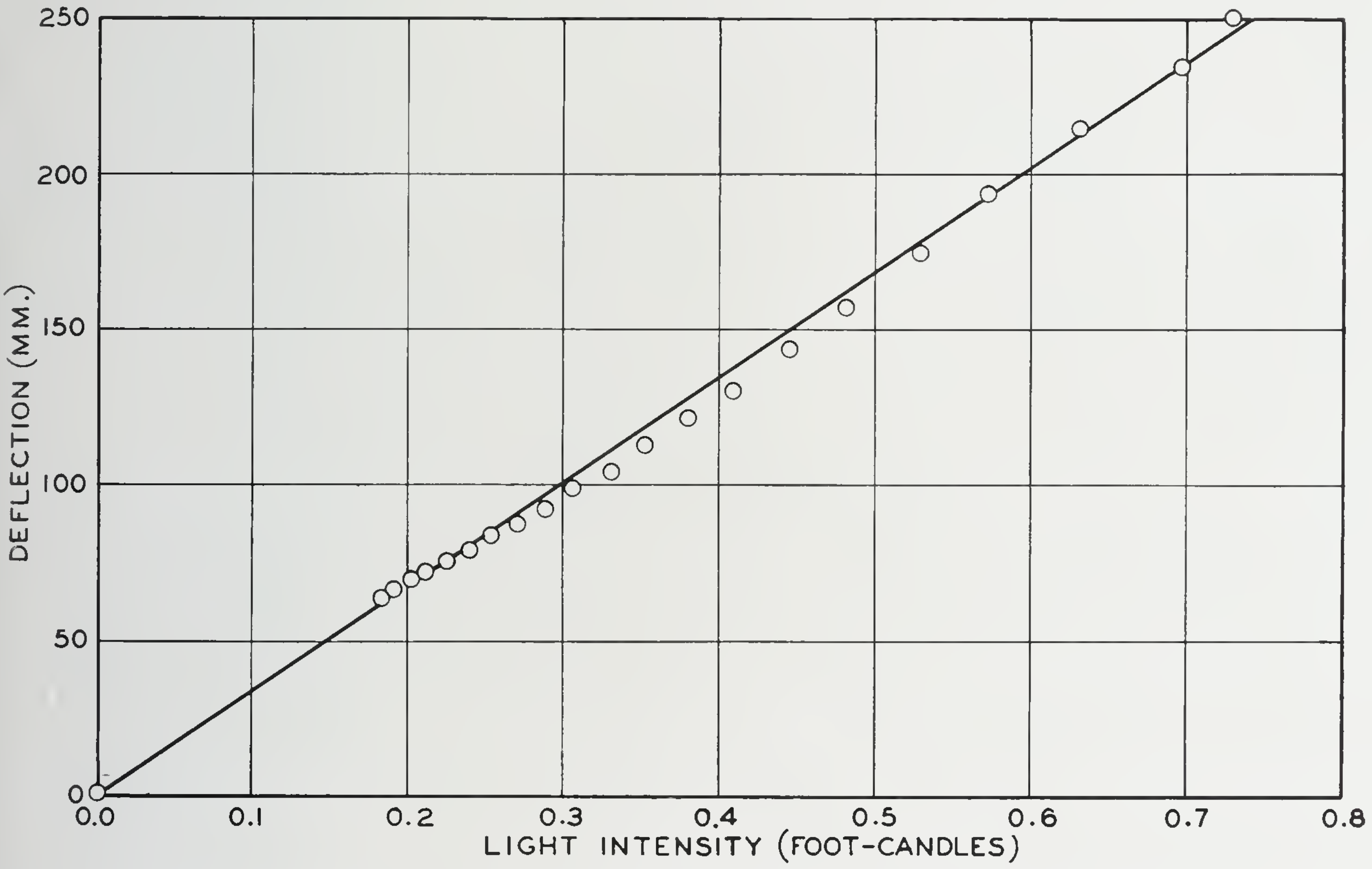

Fig. 7.—Calibration Curve For Weston Photo-Electric Cell.

The intensity of illumination used in the investigation varies from 0.75 foot-candle with no smoke to zero with complete absorption of light by smoke. For this range it may be seen that the calibration curve is approximately a straight line.

The differential manometer was calibrated against a Sargent wet test gas meter (Fig. 8).

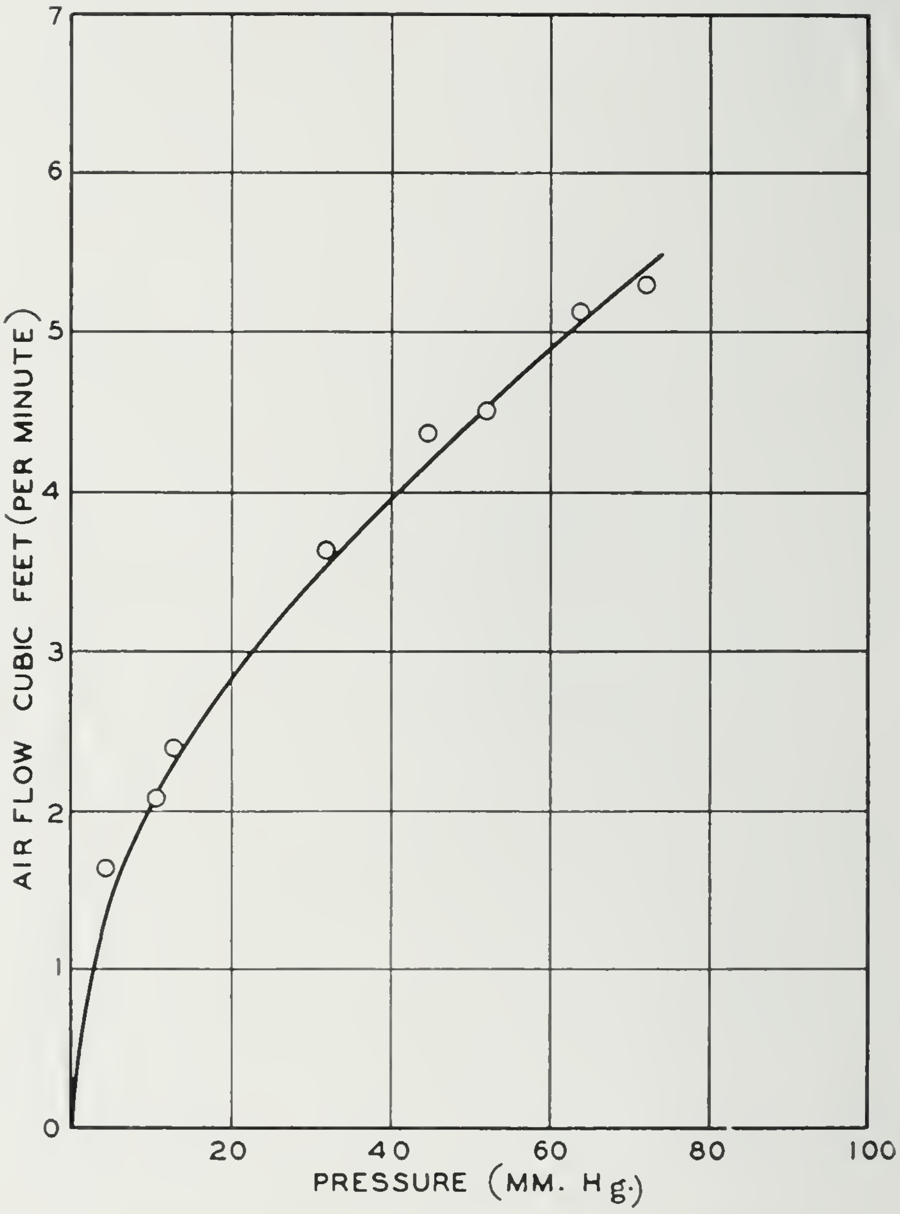

Fig. 8.—Calibration of Manometer.

Standardization of equipment with naphthalene.—In order to provide a means for determining the reproducibility of smoke index results, it was necessary to standardize the equipment by the smoke index of some common substance which would be of the identical constituency wherever obtained. Coal is heterogeneous, and hence cannot be used as a standard material from laboratory to laboratory. The material finally selected was naphthalene, the reason for its choice being that it may be obtained anywhere in a high degree of purity in the form of moth balls. An index to the purity of naphthalene is its melting point. For the desired degree of purity necessary for reproducibility of smoke index, the melting point of naphthalene should be between 80.0 and 81.5°C. Moth balls were purchased from three different sources and their melting points determined.

TABLE 2.—MELTING POINT OF NAPHTHALENE (MOTH BALLS)

Laboratory number	Sample number	Melting point °C.
0-968	N-1	80.5 to 81.5
0-969	N-2	80.5 to 81.0
0-970	N-3	80.5 to 81.0

The results, given in Table 2, show practically no variation. When burned, naphthalene gives off a very dense, black smoke and the amount per unit weight can be easily and accurately determined by the smoke index method, using a certain controlled set of burning conditions.

In determining the smoke index of naphthalene, samples exactly one gram in weight were used. The furnace was maintained at a temperature of 90°C., which is approximately 10°C. higher than the melting point of naphthalene. The air supply was held at a rate of flow of four cubic feet per minute. The weighed samples of naphthalene were placed in the container and put into the furnace and allowed to melt. As soon as the sample was entirely melted, the container was drawn to the mouth of the furnace and the naphthalene ignited by means of a Bunsen blue flame. Immediately upon ignition the container, holding the burning naphthalene, was pushed back to the middle of the furnace and galvanometer readings started. In making these tests the size and shape of the container was found to be very important as regards the rate of burning of the naphthalene. It was desirable to choose the type of a container which would give about the same rate of burning as a one gram sample of coal so that, during any stage of burning, the light passing through the absorption tube would not be completely obscured by the smoke. Since the smoke index method is based on the measurement of percentage light absorption of smoke, it is evident that the density of the smoke to be measured must be less than that necessary to give complete absorption of light. The container which was eventually found to meet these conditions was made from nickel steel, cylindrical in shape, 1 inch inside diameter, 9/16 inch inside depth, with ⅛ inch wall and 1/32 inch bottom. As stated previously, the container was placed about half way back in the furnace for the tests. The bottom of the container was ¾ inch from the bottom of the furnace tube.

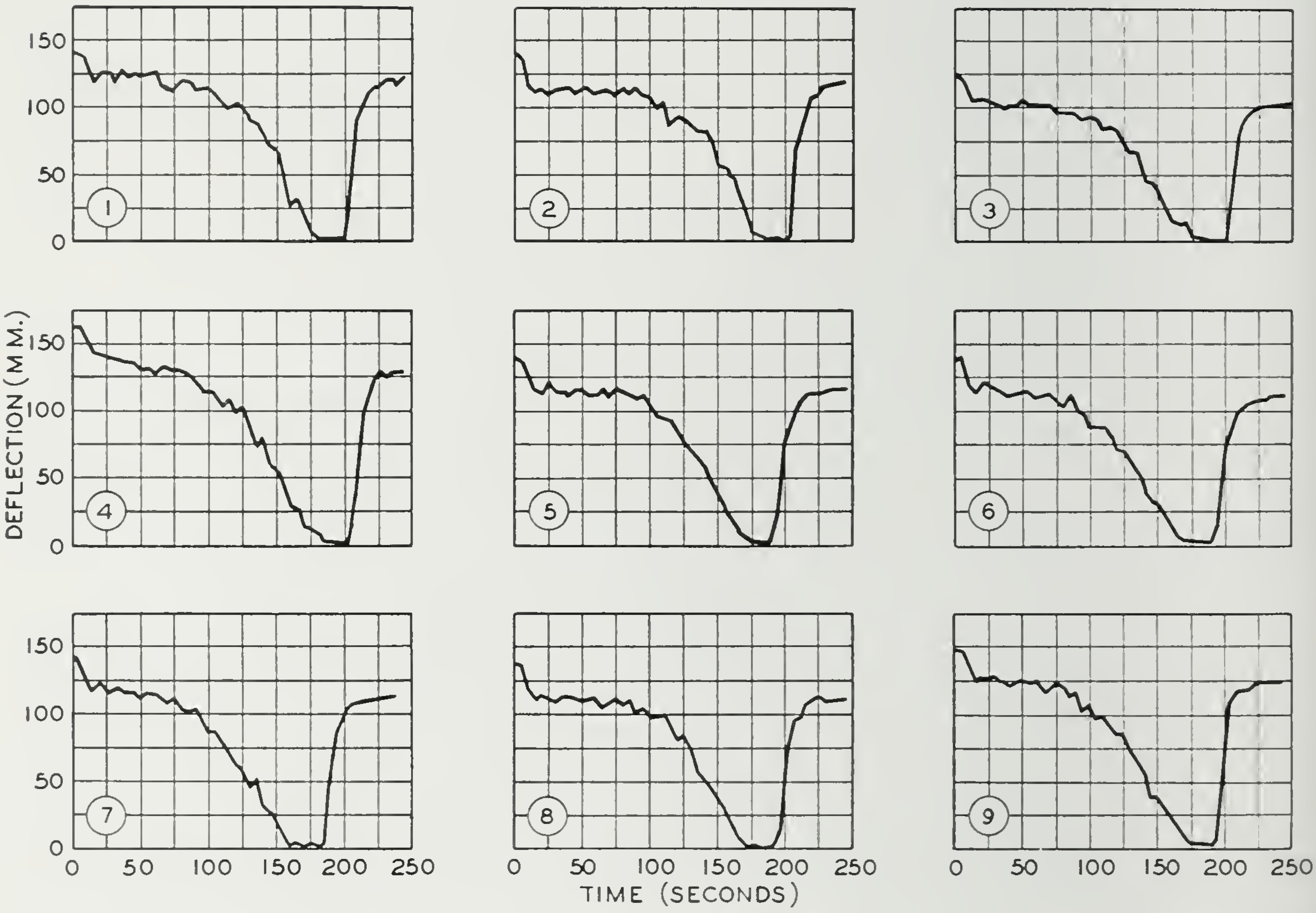

Fig. 9.—Naphthalene Tests.

A series of nine duplicate smoke index tests was made, using 1-gram samples of naphthalene, at a furnace temperature of 90°C., an air supply of 4 cubic feet per minute, following the procedure described above. The data for this series of tests are shown in Table 3 (Fig. 9). Table 4 indicates the degree of reproducibility which can be secured with the apparatus at the present time. The average deviation from the average value was 3.1 per cent, the maximum deviation being 7.1 per cent.

Table 3.—Standardization of Equipment (Naphthalene Tests)

(Data for Fig. 9)

Time (seconds)	Galvanometer deflections (millimeters)								
	1	2	3	4	5	6	7	8	9
0	141	137	128	162	141	138	138	136	147
5	140	136	124	162	137	141	141	138	148
10	130	116	106	150	124	120	125	120	137
15	118	111	106	143	116	113	117	110	123
20	127	114	106	141	114	122	120	115	129
25	127	110	104	139	122	119	116	113	126
30	118	113	101	138	115	116	118	110	126
35	129	......	99	135	115	114	118	114	124
40	122	114	102	134	114	112	116	114	124
45	126	110	103	134	117	114	116	114	120
50	123	113	107	130	116	112	113	112	125
55	125	116	102	131	112	115	115	113	124
60	126	111	101	129	113	110	115	111	124
65	116	112	100	134	117	113	111	105	119
70	114	110	100	130	111	113	108	109	117
75	114	110	98	130	119	109	112	111	123
80	120	115	97	129	115	103	103	108	121
85	119	110	98	125	112	111	101	110	114
90	113	115	96	121	110	101	102	100	116
95	113	109	92	114	111	98	95	104	102
100	113	107	94	114	103	89	86	97	108
105	111	99	92	113	96	88	86	98	97
110	104	101	85	105	95	89	78	99	99
115	99	87	86	108	92	83	74	91	92
120	101	93	84	99	86	72	64	82	86
125	99	90	76	101	78	70	60	84	86
130	91	87	67	85	72	62	46	75	74
135	88	83	66	74	65	57	52	61	67
140	78	81	48	80	55	42	34	53	58
145	72	74	46	61	47	33	28	47	39
150	68	56	40	55	40	30	16	44	39
155	47	56	31	42	25	24	8	30	31
160	28	48	19	28	21	16	3	22	23
165	32	32	15	27	11	7	3	9	14
170	21	19	15	14	7	4	0	5	5
175	7	8	6	12	4	2	2	2	2
180	4	5	3	9	3	1	1	2	2
185	1	2	0	3	3	1	5	1	1
190	1	1	0	3	4	1	55	1	1
195	3	1	0	2	24	16	91	7	7
200	2	0	2	2	82	74	105	60	65
205	30	6	36	2	99	95	108	93	110
210	90	70	77	46	109	103	110	96	117
215	106	96	94	100	115	106	111	108	117
220	114	109	98	122	114	109	113	111	119
225	114	111	100	126	114	108	113	112	122
230	118	115	102	124	115	109	114	110	123
235	120	117	102	127	117	111	114	111	123
240	117	118	102	129	117	113	114	112	124
245	123	119	103	128	118	112	......	112	124

Table 3.—Concluded.

Time (seconds)	Galvanometer deflections (millimeters)								
	1	2	3	4	5	6	7	8	9
Total	4563	4173	3759	4752	4382	4121	4094	4202	4564
Number of readings	50	49	50	50	50	50	49	50	50
A	91.3	85.2	75.2	95.0	87.6	82.4	83.5	84.0	91.3
B	132.0	128.0	115.5	145.0	129.5	125.0	126.0	124.0	135.5
X	30.8	33.4	34.9	34.5	32.4	34.1	33.7	32.3	32.6
T	245	245	245	245	245	245	245	245	245
S	7546	8180	8550	8453	7938	8355	8257	7913	7987
W	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
I (smoke index)	7550	8180	8550	8450	7940	8350	8260	7910	7990

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100.$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 4.—Standardization of Equipment (Naphthalene Tests)

Test number	Smoke index	Deviation from average	Per cent deviation from average
1	7550	—580	7.1
2	8180	+50	0.6
3	8550	+420	5.2
4	8450	+320	3.9
5	7940	—190	2.3
6	8350	+220	2.7
7	8260	+130	1.6
8	7910	—220	2.7
9	7990	—140	1.7
Average	8130	252	3.1

Procedure in making smoke index tests on coal.—In making smoke index tests to determine the total amount of smoke liberated in the burning of a given quantity of coal, either powdered or lump samples may be used. Powdered samples of coal will give more representative results if it is desired that the smoke index should be that of composite coal, but lump samples are essential if the effect of the texture of coal on its smokiness is to be considered. Furthermore, the burning of lump samples more nearly approaches the household use of coal. Lump samples of coal were therefore used for smoke index tests made in this investigation.

In order to secure duplication of results, all samples were cut from one block of coal, selected on the basis of its apparent uniformity throughout. The most uniform available coal was a column sample of No. 5 seam from Mine No. 30 of the Black Mountain Corporation, Kenvir, Kentucky, with analyses as shown in Table 5. The banded constituent of this coal block was clarain throughout.

TABLE 5.—ANALYSIS OF COAL SAMPLE USED IN SMOKE INDEX TESTS

Laboratory number C-1047	"As received"	Air dried	Moisture-free	Moisture and ash free	Unit coal
Moisture	2.3	1.5	....	....	....
Volatile matter	35.6	35.9	36.4	37.4	....
Fixed carbon	59.6	60.1	61.1	62.6	....
Ash	2.5	2.5	2.5	....	....
Total sulfur	0.8	0.8	0.8	0.8	....
B. t. u	14,251	14,362	14,581	14,960	15,013

The samples were cut to approximately one–centimeter cubes with a carborundum saw. Because of the breaking of the coal upon cutting, it was not possible to get the small cubes of equal weight although most of them were approximately so. Each sample was accurately weighed before being tested.

The procedure in making a smoke index test was to have the furnace at the desired temperature, the rate of air flow being set at some given value, and then introduce into the furnace one of the small lump samples. The sample was placed on a small shallow nickel dish H (Fig. 4), which permitted a free circulation of air around the coal. The dish was placed on the furnace tray G, which was pushed into the furnace so that the sample, when burning, occupied a position about half way back.

Since the lowest temperature (600°C.) used in making smoke index tests was well above the ignition temperature of Illinois coals (maximum recorded value of ignition temperature of Illinois coals being 558°C.[1]), the sample started to smoke soon after being put in place. Galvanometer readings were taken at five-second intervals starting the instant the sample was placed in the furnace. They were continued until the sample stopped smoking as evidenced by the change from a yellow flame to a blue flame and also by the return of the galvanometer deflection to an approximately constant value.

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[1] Arms, R. W., The ignition temperature of coal: Univ. of Illinois Eng. Exp. Sta., Bull. No. 128 (1922).

Graphical method of calculating smoke index.—A convenient method for evaluating smoke index data is to plot the densities of smoke as ordinates and the intervals of combustion as abscissae, the enclosed area representing the total amount of smoke produced. Figure 10 shows a smoke graph where actual galvanometer deflections are plotted as ordinates (zero deflection representing no light passing through the absorption tube, and initial deflection no light absorption by smoke) and periods of combustion as abscissae. A straight line is drawn between initial and final galvanometer deflections, this decrease in deflection representing the slight increase in absorption of light by a small deposition of soot on the tube windows during combustion. Consecutive points on the graph are connected by straight lines, instead of by an average curve, since the fluctuations in the smoke produced are better measured in this way.

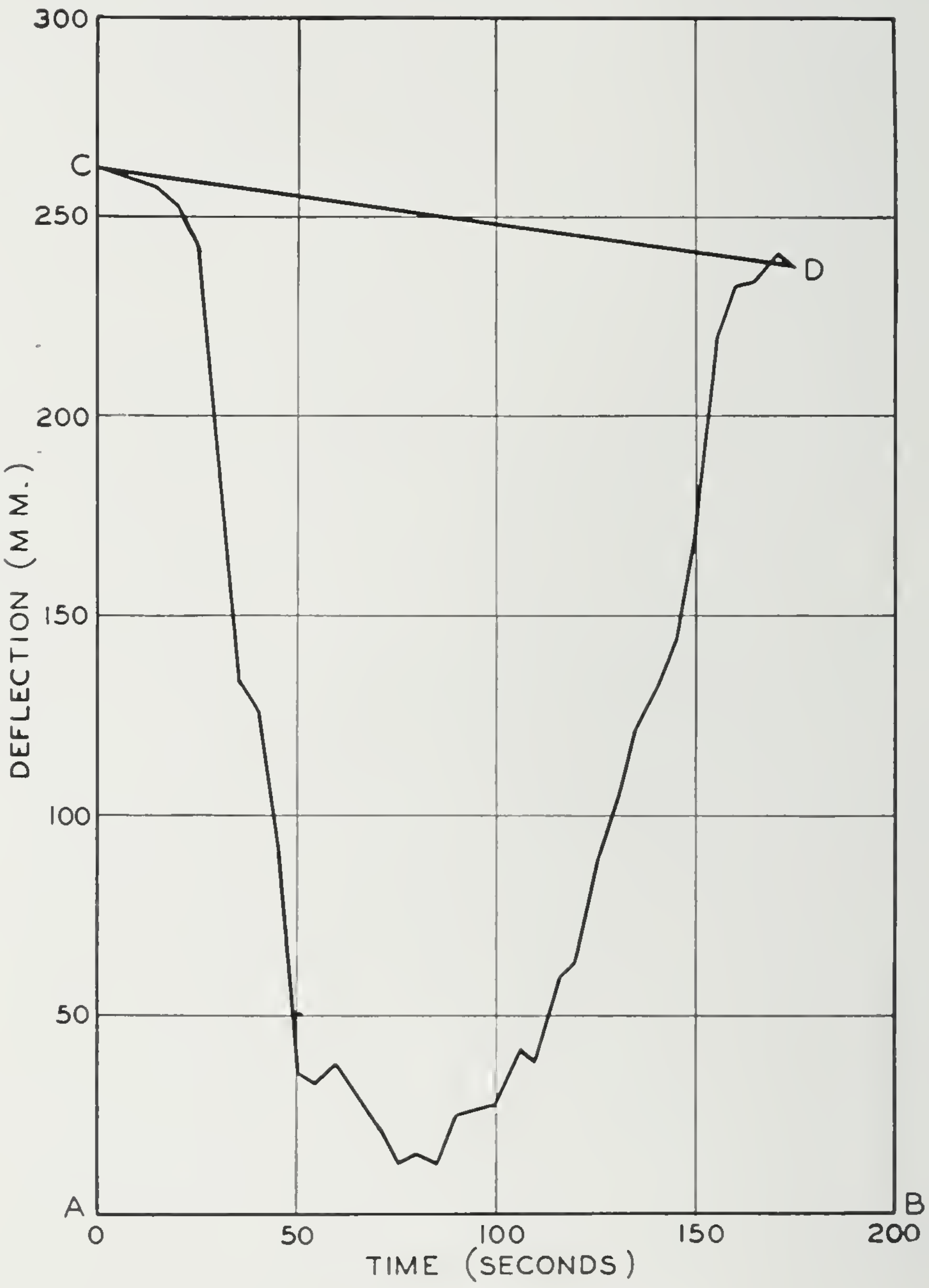

Fig. 10.—Smoke Graph.

The actual galvanometer deflections are then converted from millimeters to percentage values. The maximum light and total darkness readings were taken as 100 and 0 per cent respective for each deflection. Table 6 lists the actual experimental values of galvanometer deflections in millimeters (Fig. 10), the same galvanometer deflections in per cent, and corresponding smoke densities in per cent. Referring to figure 10, the galvanometer deflection in per cent for each point is determined by the ratio of the vertical distances between the zero-deflection line AB and this point, and between this zero deflection line and the datum line CD, through this point.

TABLE 6.—GRAPHICAL METHOD OF CALCULATING SMOKE INDEX

(DATA FOR FIGS. 10, 11, and 12)

Time (seconds)	Observed galvanometer deflection (mm)=A	Corrected initial galvanometer deflection (mm)=B	Percentage galvanometer deflection mm.=A/B x 100	Decrement in galvanometer deflection (mm)=B-A	Percentage decrement in galvanometer deflection $=\frac{B-A}{B}$ x 100
0..............	262	262.0	100.0	0.0	0.0
5..............	261	261.3	99.9	.3	.1
10.	259	260.6	99.4	1.6	.6
15..............	257	259.9	98.9	2.9	1.1
20..............	252	259.3	97.2	7.3	2.8
25..............	241	258.6	93.2	17.6	6.8
30	196	257.9	76.0	61.9	24.0
35..............	134	257.2	52.1	123.2	47.9
40..............	127	256.5	49.5	129.5	50.5
45..............	90	255.8	35.2	165.8	64.8
50..............	36	255.1	14.1	219.1	85.9
55..............	33	254.5	13.0	221.5	87.0
60..............	38	253.8	15.0	215.8	85.0
65..............	29	253.1	11.5	224.1	88.5
70..............	22	252.4	8.7	230.4	91.3
75..............	13	251.7	5.2	238.7	94.8
80..............	16	251.0	6.4	235.0	93.6
85..............	13	250.3	5.2	237.3	94.8
90..............	25	249.7	10.0	224.7	90.0
95..............	27	249.0	10.8	222.0	89.2
100..............	28	248.3	11.3	220.3	88.7
105..............	42	247.6	17.0	205.6	83.0
110..............	39	246.9	15.8	207.9	84.2
115..............	59	246.2	24.0	187.2	76.0
120..............	64	245.5	26.1	181.5	73.9
125..............	89	244.9	36.3	155.9	63.7
130..............	103	244.2	42.2	141.2	57.8
135..............	122	243.5	50.1	121.5	49.9
140..............	130	242.8	53.5	112.8	46.5
145..............	145	242.1	59.9	97.1	40.1
150..............	172	241.4	71.3	69.4	28.7
155..............	219	240.7	91.0	21.7	9.0
160..............	233	240.0	97.1	7.0	2.9
165..............	234	239.4	97.7	5.4	2.3
170..............	240	238.7	100.0	0.0	0.0
175..............	238	238	100.0	0.0	0.0

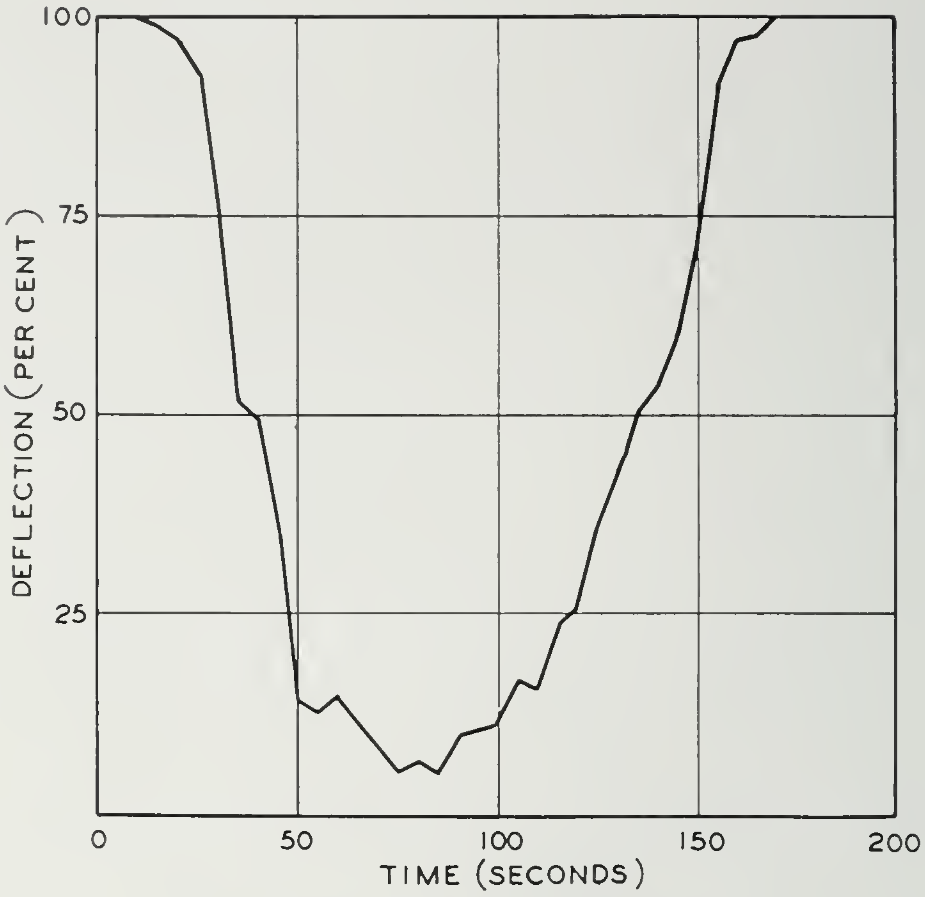

Fig. 11.—Smoke Graph.

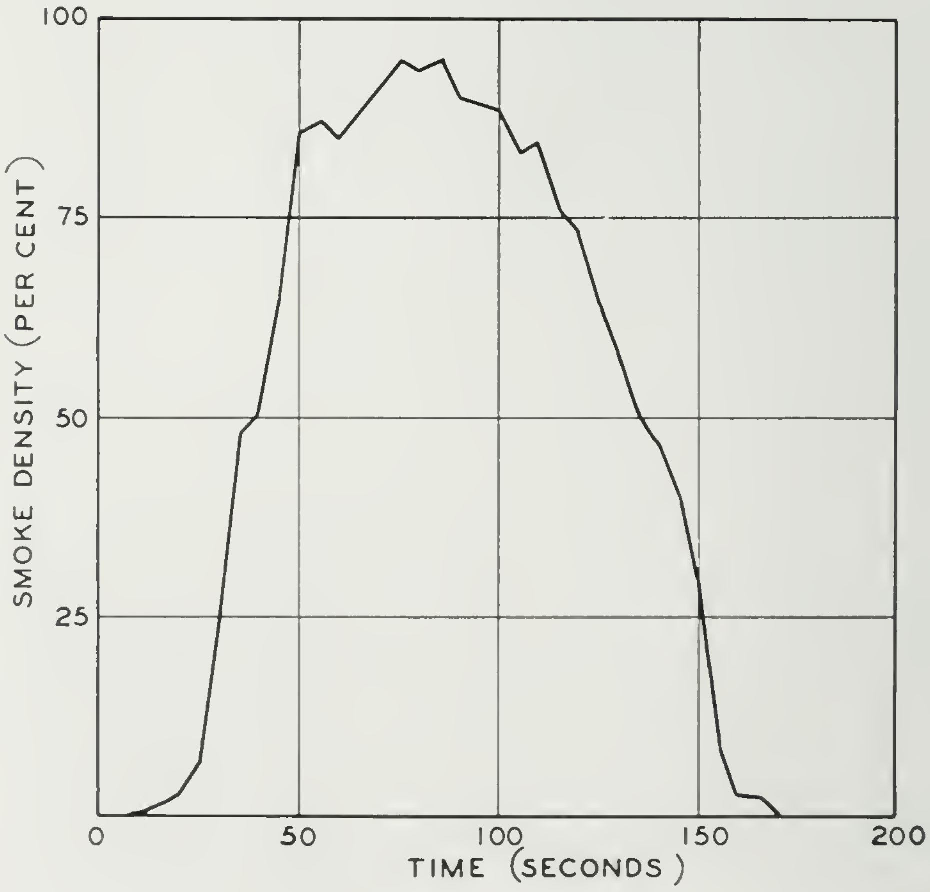

Fig. 12.—Smoke Graph.

Since the galvanometer deflection is a measure of the light transmitted rather than the light absorbed by the smoke, the smoke density percentage is the complement of the per cent galvanometer deflection (100 per cent minus the per cent galvanometer deflection).

Figures 11 and 12 show respectively graphs of galvanometer deflection in per cent and smoke density in per cent for the data recorded in Table 6. The smoke index of the sample in question can then be determined by measuring the area enclosed in its per cent smoke density-time graph by means of a planimeter, and dividing this area by the weight of the sample tested. Another approximate method might be to cut cardboard (made especially for such type of work) of the same shape as the per cent smoke density-time curves and weighing the cards. The ratio of the weight of such a card to the weight of a card consisting of the total area available in each instance, would be the average smoke density over the total time of combustion. This ratio (in terms of per cent) multiplied by the time of combustion and divided by the weight (in grams) of the sample tested, would give the smoke index.

In determining the smoke density-time graphs, a more exact method would be to use an automatic recorder. The expense of such an apparatus prohibited its use in this investigation. The areas generated by such a recorder might be evaluated by either of the above described methods.

Algebraic method of calculating smoke index.—Since the graphical method of calculating smoke index is subject to certain errors due to inaccuracies in measuring areas and, in addition, requires considerable time, it was thought advisable to use an algebraic or numerical method of calculation. All of the values of smoke index given in this report have been calculated by this method which is as follows: The sum of all the galvanometer readings over the period of smoke production is obtained, and the average galvanometer deflection is then calculated by dividing this sum by the total number of readings taken. Let this average galvanometer deflection be called A. The next step is to determine the mean value of the initial and final deflections. Let this mean value be called B. Then the average smoke density in per cent, during the total time of combustion of the sample, will be this mean deflection B, minus the average galvanometer deflection A, the difference being divided by the deflection B, and multiplied by 100; that is, average smoke density $(X) = \frac{B - A \times 100.}{B}$ This value of average smoke density when multiplied by the total time of combustion T gives the value of the area S, enclosed by the smoke density-time curve, and the area S represents the total amount of smoke given off by the sample tested. Then in order to convert to a common basis for comparison, this area S is divided by the weight of the sample W, which gives the smoke index I of the sample in units of per cent smoke density times seconds, per gram, or

$$I = S/W = \frac{\%\ S.\ D. \times\ T}{W}$$

This gives a simple and reliable method of calculating the smoke index of a fuel.

CHAPTER V—RESULTS

EFFECT OF AIR SUPPLY

It is well known that the rate and the degree of completeness of the combustion of any fuel depends in part upon the supply of oxygen (air) admitted into the combustion chamber. Therefore it was deemed advisable to investigate the effect of the air supply on the amount of smoke produced by the samples burned in the smoke index tests. To this end a series of 25 tests were made using air supplies of 2, 3, 4, 5, and 6 cubic feet per minute, five tests being made for each rate of air supply. The samples used in these tests were all cut from the same block of coal so that individual sample differences might be minimized. Their weights varied from 0.69 to 1.13 grams, most of them weighing between 0.90 and 1.10 grams. They were all approximately cubical in shape. The furnace temperature was held at 600°C., and the tests were carried out in the usual manner except that the rate of air supply was changed every five tests.

The data taken during these tests are tabulated in Tables 7, 8, 9, 10, and 11. At the bottom of each table are given the essentials of the calculations involved in determining the smoke indices. The last row of each table gives the value of smoke index for each of the five tests. These results are summarized in Table 12 (Fig. 13) which gives the individual values of smoke index for each of the five tests, for each air supply, and also the average value of smoke index for each air supply. They indicate that increased air supply decreases the amount of smoke given off. For air supplies less than 4 cubic feet per minute, there was quite an appreciable amount of soot deposited on the inner walls of the apparatus. For air supplies of 4 cubic feet per minute, or greater, this deposit was small.

The results indicate only a small variation of smoke index with variation of the air supply from 3 to 5 cubic feet per minute. Therefore for all subsequent tests the value of air supply was set at 4 cubic feet per minute, which is sufficiently high to avoid excessive soot.

TABLE 7.—EFFECT OF AIR SUPPLY (2.0 CUBIC FEET PER MINUTE) ON SMOKE INDEX

Time (seconds)	Galvanometer deflections (millimeters)				
	1	2	3	4	5
0	243	231	248	224	219
5	241	221	240	223	213
10	237	209	239	218	197
15	228	165	237	206	178
20	201	121	233	181	152
25	185	98	226	153	123
30	131	72	210	105	142
35	87	19	190	24	31
40	58	11	150	19	6
45	59	17	26	13	11
50	67	19	29	16	13
55	22	26	22	18	18
60	5	77	17	19	26
65	14	66	47	14	24
70	29	86	57	15	17
75	46	50	91	41	56
80	16	33	56	45	109
85	15	35	50	36	185
90	59	99	57	34	201
95	99	147	61	88	207
100	163	137	29	130	209
105	181	141	39	139	....
110	183	160	74	106	....
115	186	175	95	157	....
120	202	199	149	206	....
125	221	212	202	210	....
130	235	216	223	....	....
135	....	218	225	....	....
140	....	219	....	....	....
145	....	....	....	....	....
150	....	....	....	....	....
Total	3413	3479	3522	2640	2337
Number readings	27	29	28	26	21
A	126.4	119.9	125.8	101.5	111.3
B	239.0	225.0	236.5	217.0	214.0
X	47.1	46.7	46.8	53.2	48.0
T	130	140	135	125	100
S	6123	6538	6318	6650	4800
W	1.03	1.04	1.03	1.06	.77
I (smoke index)	5940	6290	6130	6270	6230

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 8.—EFFECT OF AIR SUPPLY (3.0 CUBIC FEET PER MINUTE) ON SMOKE INDEX

Time (seconds)	Galvanometer deflections (millimeters)				
	1	2	3	4	5
0	243	219	251	253	213
5	240	218	253	252	210
10	238	217	260	246	209
15	220	208	240	229	208
20	200	195	190	186	196
25	65	171	126	61	178
30	19	141	103	13	138
35	16	123	106	17	99
40	15	89	54	14	81
45	33	69	59	19	73
50	46	27	48	41	48
55	53	23	61	78	38
60	39	24	89	82	15
65	44	33	61	97	38
70	105	40	32	87	39
75	141	49	49	104	27
80	121	47	39	141	43
85	122	77	50	74	81
90	151	53	76	42	96
95	183	88	110	104	76
100	207	97	126	114	137
105	225	52	143	155	178
110	227	38	220	211	187
115	....	70	235	219	....
120	....	110	....	....	....
125	....	109	....	....	....
130	....	154	....	....	....
135	....	184	....	....	....
140	....	185	....	....	....
145	....	....	....	....	....
150	....	....	....	....	....
Total	2953	3110	2981	2839	2608
Number readings	23	29	24	24	23
A	128.3	107.2	124.2	118.2	113.3
B	235.0	202.0	243.0	236.0	200.0
X	45.4	46.9	48.9	49.9	43.3
T	110	140	115	115	110
S	4994	6566	5624	5739	4763
W	.99	1.13	.99	1.03	.76
I (smoke index)	5040	5810	5680	5570	6270

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time in seconds.
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 9.—Effect of Air Supply (4.0 Cubic Feet per Minute) on Smoke Index

Time (seconds)	Galvanometer deflections (millimeters)				
	1	2	3	4	5
0	198	246	229	232	224
5	195	245	228	222	223
10	194	242	223	224	221
15	194	236	200	229	215
20	192	230	160	209	201
25	184	217	123	194	176
30	182	190	78	75	139
35	171	164	51	17	104
40	126	135	41	15	62
45	88	95	32	25	36
50	69	65	47	33	24
55	56	75	27	29	38
60	45	49	12	38	15
65	41	84	18	61	26
70	63	110	24	83	47
75	53	106	22	109	35
80	53	112	109	131	60
85	102	113	101	132	121
90	94	129	82	123	132
95	90	147	118	113	149
100	171	80	149	118	182
105	182	104	177	138	197
110	186	155	198	166	....
115	....	194	204	189	....
120	....	220	202	192	....
125	....	238	....	....	....
130	....	237	....	....	....
135	....	....	....	....	....
Total	2929	4218	2855	3097	2627
Number readings	23	27	25	25	22
A	127.3	156.2	114.2	123.9	119.4
B	192.0	241.5	215.5	212.0	210.5
X	33.7	35.3	47.0	41.6	43.3
T	110	130	120	120	105
S	3707	4589	5640	4992	4547
W	.69	.86	1.06	1.00	.80
I (smoke index)	5370	5340	5320	4990	5680

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100.$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample in grams.
I = smoke index = S/W.

Table 10.—Effect of Air Supply (5.0 Cubic Feet per Minute) on Smoke Index

Time (seconds)	Galvanometer deflections (millimeters)				
	1	2	3	4	5
0	236	213	209	207	213
5	235	211	205	206	209
10	233	209	194	204	194
15	233	201	167	186	181
20	231	175	137	137	142
25	222	140	93	114	104
30	197	105	76	113	78
35	167	77	72	104	52
40	138	59	70	85	39
45	128	42	73	64	41
50	107	32	69	53	26
55	94	31	61	47	18
60	94	36	64	37	30
65	86	39	64	67	42
70	72	38	58	77	61
75	77	40	61	86	87
80	54	111	90	121	80
85	51	106	107	123	88
90	54	104	133	144	104
95	66	103	140	182	142
100	90	107	130	194	158
105	105	126	169	....	159
110	134	149	185	....	161
115	134	177	186	....	162
120	126	194	....	....	162
125	167	191	....	....	167
130	211	....	....	....	....
135	225	....	....	....	....
140	....	....	....	....	....
Total	3967	3016	2813	2551	2900
Number readings	28	26	24	21	26
A	141.7	116.0	117.2	121.5	111.5
B	230.5	202.0	197.5	200.5	190.0
X	38.5	42.6	40.7	39.4	41.3
T	135	125	115	100	125
S	5197	5325	4681	3940	5163
W	.96	.97	.94	.72	1.02
I (smoke index)	5410	5490	4980	5470	5060

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 11.—EFFECT OF AIR SUPPLY (6.0 CUBIC FEET PER MINUTE) ON SMOKE INDEX

Time (seconds)	Galvanometer deflections (millimeters)				
	1	2	3	4	5
0	215	212	203	202	195
5	212	211	202	196	193
10	202	211	200	176	192
15	195	206	187	142	188
20	175	195	170	111	175
25	154	175	155	75	156
30	128	153	125	62	133
35	119	138	67	79	105
40	129	110	39	101	107
45	89	87	44	104	92
50	62	71	73	85	93
55	96	68	77	111	93
60	82	58	85	118	97
65	88	70	84	124	81
70	74	104	89	103	61
75	50	129	97	123	55
80	74	147	93	151	78
85	65	142	106	167	73
90	139	131	132	169	90
95	173	137	154		112
100	178	137	163		137
105		101	165		151
110		125			167
115		167			169
120		172			
125		172			
130		173			
135		174			
140					
Total	2699	3976	2710	2399	2993
Number readings	21	28	22	19	24
A	128.5	142.0	123.2	126.3	124.7
B	196.5	193.0	184.0	185.5	182.0
X	34.6	26.4	33.0	32.0	32.0
T	100	135	105	90	115
S	3460	3564	3465	2880	3680
W	.87	.99	.91	.83	.91
I	3980	3600	3810	3470	4040

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

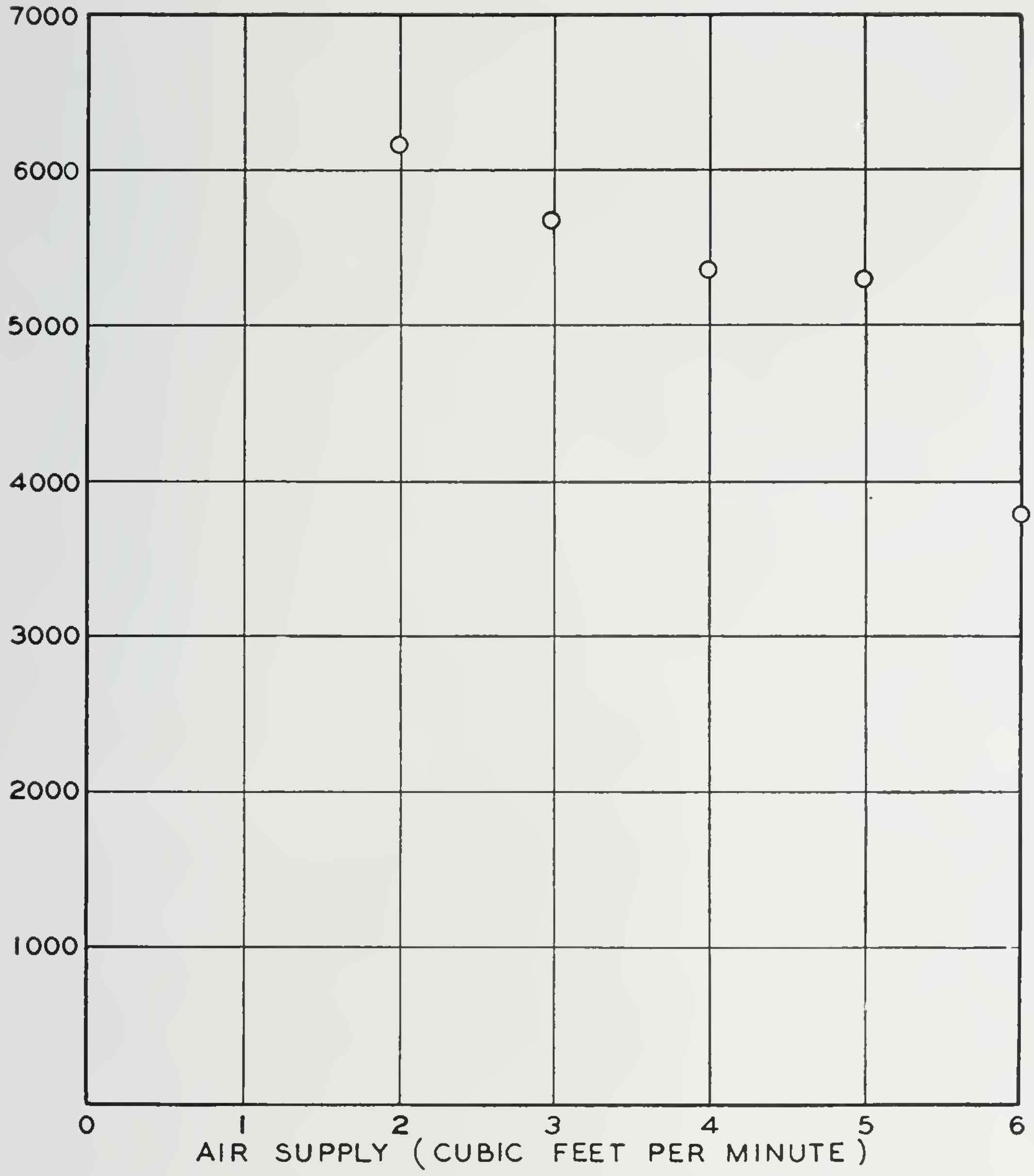

Fig. 13.—Effect of Air Supply on Smoke Index.

Table 12.—Effect of Air Supply on Smoke Index (Summary)

(Data for Fig. 13)

Smoke Indices

Test number	Air supply—cu. ft. per minute				
	2.0	3.0	4.0	5.0	6.0
1.	5940	5040	5370	5410	3980
2.	6290	5810	5340	5490	3600
3.	6130	5680	5320	4980	3810
4.	6270	5570	4990	5470	3470
5.	6230	6270	5680	5060	4040
Average	6170	5670	5340	5280	3780

EFFECT OF TEMPERATURE

The amount and character of smoke given off during combustion depends also, in part, on the temperature of the furnace. After determining a suitable rate of air supply, a series of tests was made to determine the temperature at which most accurate and reproducible results were obtained. The highest temperature of the upper portion of the bed of coal in a domestic furnace is from 600°C. to 1000°C.; accordingly, this range was investigated, in five steps of 100°C. each. Ten tests were made at each temperature, using duplicate samples. In order to minimize sample differences, all samples were taken from the same block of coal. The ignition temperature of the sample was well below the lowest temperature investigated. All samples were approximately cubical in shape, and their weights varied from 0.65 to 1.30 grams. For such small samples, the effect of such differences in size appears to be negligible.

The tests were carried out in the manner described previously, the air supply being held at a value of 4 cubic feet per minute. The temperature was raised 100°C. after every ten tests, starting at 600°C. and continuing to 1000°C. The data from these tests are shown in Tables 13, 14, 15, 16, and 17. At the bottom of each table are shown the calculations for smoke indices and the last row in each table gives the ten values of smoke index obtained for that specified temperature. Table 18 summarizes these results, giving the ten individual values of smoke index for each temperature used and, also, the average value of the smoke index for each temperature (Fig. 14).

The results of this series of tests show clearly a distinct decrease in smoke index with increasing furnace temperature, the average smoke index for 600°C. being 6390 and for 1000°C. being 2150, which is only one-third as great. This decrease takes place in a fairly uniform manner, although it is less pronounced in the middle than at the ends of the temperature range.

As regards the individual values of smoke indices, Table 18 shows that by far the most reproducible results were obtained at a temperature of 600°C. Since the values of smoke indices are much smaller at higher temperatures, any errors caused by irregularities in combustion will cause a greater per cent error. The temperature of 600°C. was selected for all tests since it gives the most reproducible results.

Table 13.—Effect of Temperature (600°C.) on Smoke Index (Air Supply—4 Cubic Feet per Minute)

Time (seconds)	Galvanometer deflections (millimeters)										
	1	2	3	4	5	6	7	8	9	10	11
0	262	236	257	223	233	211	247	236	231	239	204
5	261	234	253	222	232	209	242	232	229	235	203
10	259	231	251	221	231	206	240	195	221	226	202
15	257	224	247	217	230	194	222	130	212	213	196
20	252	209	245	160	229	156	192	129	204	171	183
25	241	182	235	90	226	105	150	140	180	130	153
30	196	145	211	72	213	59	105	120	161	90	85
35	134	106	171	112	186	31	65	84	110	62	46
40	127	76	122	94	159	20	47	51	80	47	21
45	90	51	95	70	117	18	30	35	57	42	15
50	36	31	62	59	94	12	28	31	47	38	21
55	33	22	49	49	81	12	19	24	36	32	14
60	38	15	31	52	54	37	11	13	45	32	28
65	29	12	21	39	42	38	13	12	37	32	59
70	22	10	14	26	41	42	17	24	18	40	69
75	13	17	14	29	31	56	17	23	29	55	55
80	16	33	16	19	35	61	30	47	74	68	80
85	13	35	45	28	29	81	42	69	94	72	110
90	25	50	26	45	27	110	61	81	107	89	125
95	27	57	33	39	21	146	90	90	98	107	186
100	28	77	54	39	46	185	131	114	99	113	197
105	42	99	76	60	40	204	153	126	115	147	193
110	39	114	58	55	24	......	167	147	128	190	......
115	59	144	95	82	24	......	182	154	135	209	......
120	64	184	155	104	41	......	187	164	195	......	......
125	89	210	217	123	63	......	204	210	218	......	......
130	103	216	235	154	62	......	236	219	......	......	......
135	122	......	......	143	89	......	......	......	......	......	......
140	130	......	......	162	104	......	......	......	......	......	......
145	145	......	......	161	135	......	......	......	......	......	......
150	172	......	......	204	210	......	......	......	......	......	......
155	219	......	......	......	218	......	......	......	......	......	......
160	233	......	......	......	216	......	......	......	......	......	......
165	234	......	......	......	......	......	......	......	......	......	......
170	240	......	......	......	......	......	......	......	......	......	......
175	238	......	......	......	......	......	......	......	......	......	......
Total	4488	3020	3288	3153	3783	2193	3128	2900	3160	2679	2445
Number readings	36	27	27	31	33	22	27	27	26	24	22
A	124.7	111.9	121.8	101.7	114.6	99.7	115.9	107.4	121.5	111.6	111.1
B	250.0	226.0	246.0	213.5	224.5	207.5	241.5	227.5	224.5	224.0	198.5
X	50.1	50.5	50.5	52.4	49.0	52.0	52.0	52.8	45.9	50.2	44.0
T	175	130	130	150	160	105	130	130	125	115	105
S	8768	6565	6565	7860	7840	5460	6760	6864	5738	5773	4620
W	1.30	1.06	1.08	1.27	1.24	.82	1.03	1.02	.96	.89	.74
I (smoke index)	6740	6190	6080	6190	6320	6660	6560	6730	5980	6490	6240

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 14.—EFFECT OF TEMPERATURE (700°C.) ON SMOKE INDEX (AIR SUPPLY—4 CUBIC FEET PER MINUTE)

Time (seconds)	Galvanometer deflections (millimeters)									
	1	2	3	4	5	6	7	8	9	10
0	222	220	195	197	207	239	251	240	229	222
5	220	209	182	152	130	120	238	238	226	217
10	195	134	110	82	71	66	218	234	222	216
15	70	63	59	51	53	55	197	226	87	190
20	24	35	39	42	48	47	47	112	48	60
25	20	34	41	36	45	44	34	61	60	39
30	22	79	36	31	59	38	47	72	54	36
35	31	98	61	31	73	35	66	67	55	43
40	41	81	91	42	55	55	81	90	104	58
45	42	84	105	61	51	84	91	99	115	71
50	57	43	112	103	43	84	108	68	148	82
55	74	31	131	117	57	100	81	63	132	86
60	72	56	140	132	42	127	70	76	115	116
65	96	84	145	148	67	127	91	76	123	125
70	72	96	154	149	107	120	110	69	138	120
75	61	131	161	158	66	170	123	106	153	113
80	135	179	174	172	49	197	183	103	163	87
85	174	189	......	......	87	......	208	138	182	72
90	182	......	......	......	137	......	......	158	184	106
95	......	......	......	......	......	......	......	171	186	151
100	......	......	......	......	......	......	......	172	......	152
105	......	......	......	......	......	......	......	......	......	158
110	......	......	......	......	......	......	......	......	......	163
115	......	......	......	......	......	......	......	......	......	165
120	......	......	......	......	......	......	......	......	......	167
125	......	......	......	......	......	......	......	......	......	168
130	......	......	......	......	......	......	......	......	......	170
135	......	......	......	......	......	......	......	......	......	171
140	......	......	......	......	......	......	......	......	......	171
145	......	......	......	......	......	......	......	......	......	172
150	......	......	......	......	......	......	......	......	......	......
Total	1810	1846	1936	1704	1447	1708	2244	2639	2724	3867
Number readings	19	18	17	17	19	17	18	21	20	30
A	95.3	102.6	113.9	100.2	76.2	100.5	124.7	125.7	136.2	128.9
B	202.0	204.5	184.5	184.5	172.0	218.0	229.5	206.0	207.5	197.0
X	52.8	49.8	38.3	45.7	55.7	53.9	45.7	39.0	34.4	34.6
T	90	85	80	80	90	80	85	100	95	145
S	4752	4233	3064	3656	5013	4312	3885	3900	3268	5017
W	1.14	.87	.77	.70	1.01	.87	.83	.93	.75	.88
I (smoke index)	4170	4870	3980	5220	4960	4960	4680	4190	4360	5700

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 15.—EFFECT OF TEMPERATURE (800°C.) ON SMOKE INDEX (AIR SUPPLY—4 CUBIC FEET PER MINUTE)

Time (seconds)	Galvanometer deflections (millimeters)									
	1	2	3	4	5	6	7	8	9	10
0......	195	214	200	201	194	197	192	180	184	187
5......	190	210	197	194	191	190	185	140	180	184
10......	160	120	121	165	170	174	120	75	145	133
15......	92	63	56	71	103	115	33	32	85	82
20......	50	26	43	40	81	75	31	27	49	26
25......	29	27	38	24	54	68	45	40	46	39
30......	46	48	67	51	49	60	74	41	59	34
35......	47	61	76	68	57	62	75	55	60	63
40......	56	42	86	47	43	71	64	67	71	69
45......	51	50	71	45	40	104	97	108	30	117
50......	64	59	99	75	20	87	69	119	47	90
55......	95	77	110	85	38	87	64	124	63	126
60......	88	88	109	100	77	116	120	135	48	147
65......	103	74	108	119	62	107	130	141	51	168
70......	97	94	145	132	75	132	121	144	67	....
75......	126	110	168	133	94	155	153	150	91	....
80......	149	125	174	135	110	157	166	152	135	....
85......	150	143	175	146	137	159	166	153	142	....
90......	....	149	176	161	....	....	168	....	142	....
95......	....	148	177	....	....	....	....	....	142	....
100......	....	147	....	....	....	....	....	....	143	....
105......	....	145	....	....	....	....	....	....	146	....
110......	....	142	....	....	....	....	....	....	....	....
115......	....	144	....	....	....	....	....	....	....	....
120......	....	145	....	....	....	....	....	....	....	....
125......	....	146	....	....	....	....	....	....	....	....
130......	....	149	....	....	....	....	....	....	....	....
135......	....	....	....	....	....	....	....	....	....	....
Total..	1788	2946	2396	2010	1595	2116	2073	1883	2126	1465
Number readings	18	27	20	19	18	18	19	18	22	14
A.....	99.3	109.1	119.8	105.8	88.6	117.6	109.1	104.6	96.6	104.6
B.....	172.5	181.5	188.5	181.0	165.5	178.0	180.0	166.5	165.0	177.5
X.....	42.4	39.9	36.4	41.5	46.5	33.9	39.4	37.2	41.5	41.1
T.....	85	130	95	90	85	85	90	85	105	65
S.....	3604	5187	3458	3735	3953	2882	3546	3162	4358	2672
W....	1.04	1.15	.92	1.03	.96	.74	.87	.93	.80	.75
I (smoke index)	3470	4510	3760	3630	4120	3890	4080	3400	5450	3560

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) $= \frac{B - A}{B} \times 100.$

T = total time in seconds.
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 16.—EFFECT OF TEMPERATURE (900°C.) ON SMOKE INDEX (AIR SUPPLY—4 CUBIC FEET PER MINUTE)

Time (seconds)	Galvanometer deflections (millimeters)									
	1	2	3	4	5	6	7	8	9	10
0......	195	205	205	213	211	202	210	200	201	200
5......	190	202	199	212	210	200	208	131	196	184
10......	115	160	145	195	135	145	193	35	165	150
15......	18	45	74	113	31	41	82	19	59	96
20......	18	22	36	12	14	19	12	48	31	69
25......	55	41	48	8	17	40	34	81	49	103
30......	71	31	56	37	36	66	70	117	71	82
35......	64	39	100	37	72	75	55	80	40	69
40......	55	42	92	42	122	85	101	71	25	102
45......	104	61	84	73	123	70	127	79	44	127
50......	88	7	91	30	134	13	134	105	75	141
55......	106	13	90	60	146	50	136	131	104	155
60......	127	35	130	126	152	101	148	153	116	167
65......	142	70	142	146	157	133	161	161	124	....
70......	140	95	153	152	157	139	169	....	129	....
75......	142	145	154	153	158	138	169	....	132	....
80......	147	147	155	....	158	139	169	....	133	....
85......	....	....	....	....	160	140	170	....	....	....
90......	....	....	....	....	....	....	171	....	....	....
95......	....	....	....	....	....	....	171	....	....	....
100......	....	....	....	....	....	....	172	....	....	....
105......	....	....	....	....	....	....	173	....	....	....
110......	....	....	....	....	....	....	....	....	....	....
Total..	1777	1360	1954	1609	2193	1796	3035	1411	1694	1645
Number readings	17	17	17	16	18	18	22	14	17	13
A.....	104.5	80.0	114.9	100.6	121.8	99.8	138.0	100.8	99.6	126.5
B.....	171.0	176.0	180.0	183.0	185.5	171.0	191.5	180.5	167.0	183.5
X.....	38.9	54.5	36.2	45.0	34.3	41.6	27.9	44.2	40.4	31.1
T.....	80	80	80	75	85	85	105	65	80	60
S.....	3112	4360	2896	3375	2916	3536	2930	2873	3232	1866
W....	1.02	1.17	1.04	.92	.91	.93	.75	.85	1.06	.75
I (smoke index)	3050	3730	2780	3670	3200	3800	3910	3380	3050	2490

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time in seconds.
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 17.—Effect of Temperature (1000°C.) on Smoke Index (Air Supply—4 Cubic Feet per Minute)

Time (seconds)	Galvanometer deflections (millimeters)									
	1	2	3	4	5	6	7	8	9	10
0......	186	187	202	181	189	182	189	200	195	179
5......	182	183	197	178	187	175	180	188	190	171
10......	130	160	100	116	156	60	115	157	120	130
15......	133	25	49	33	21	10	36	61	30	13
20......	125	18	76	55	24	39	21	58	57	4
25......	87	52	142	91	106	69	35	25	70	20
30......	96	64	132	116	157	118	79	52	66	68
35......	136	1	95	141	167	114	111	88	91	108
40......	163	20	162	165	176	80	120	115	136	141
45......	179	71	161	168	177	61	139	156	157	144
50......	179	129	180	171	179	125	156	169	174	147
55......	181	153	189	188	....	155	163	....	178	151
60......	....	154	190	....	....	162	166	....	180	....
65......	....	156	....	....	....	....	....	....	....	....
70......	....	159	....	....	....	....	....	....	....	....
75......	....	161	....	....	....	....	....	....	....	....
80......	....	162	....	....	....	....	....	....	....	....
85......	....	....	....	....	....	....	....	....	....	....
Total..	1777	1855	1875	1603	1539	1350	1510	1269	1644	1276
Number readings	12	17	13	12	11	13	13	11	13	12
A.....	148.1	109.1	144.2	133.6	139.9	103.8	116.2	115.4	126.5	106.3
B.....	183.5	174.5	196.0	184.5	184.0	172.0	177.5	184.5	187.5	165.0
X.....	19.3	37.5	26.4	27.6	24.0	39.7	34.5	37.5	32.5	35.6
T.....	55	80	60	55	50	60	60	50	60	55
S.....	1062	3000	1584	1518	1200	2382	2070	1875	1950	1958
W....	.65	1.00	.78	.78	.84	1.07	.98	.90	.71	.85
I (smoke index)	1630	3000	2030	1950	1430	2230	2110	2080	2750	2300

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100.$
T = total time in seconds.
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

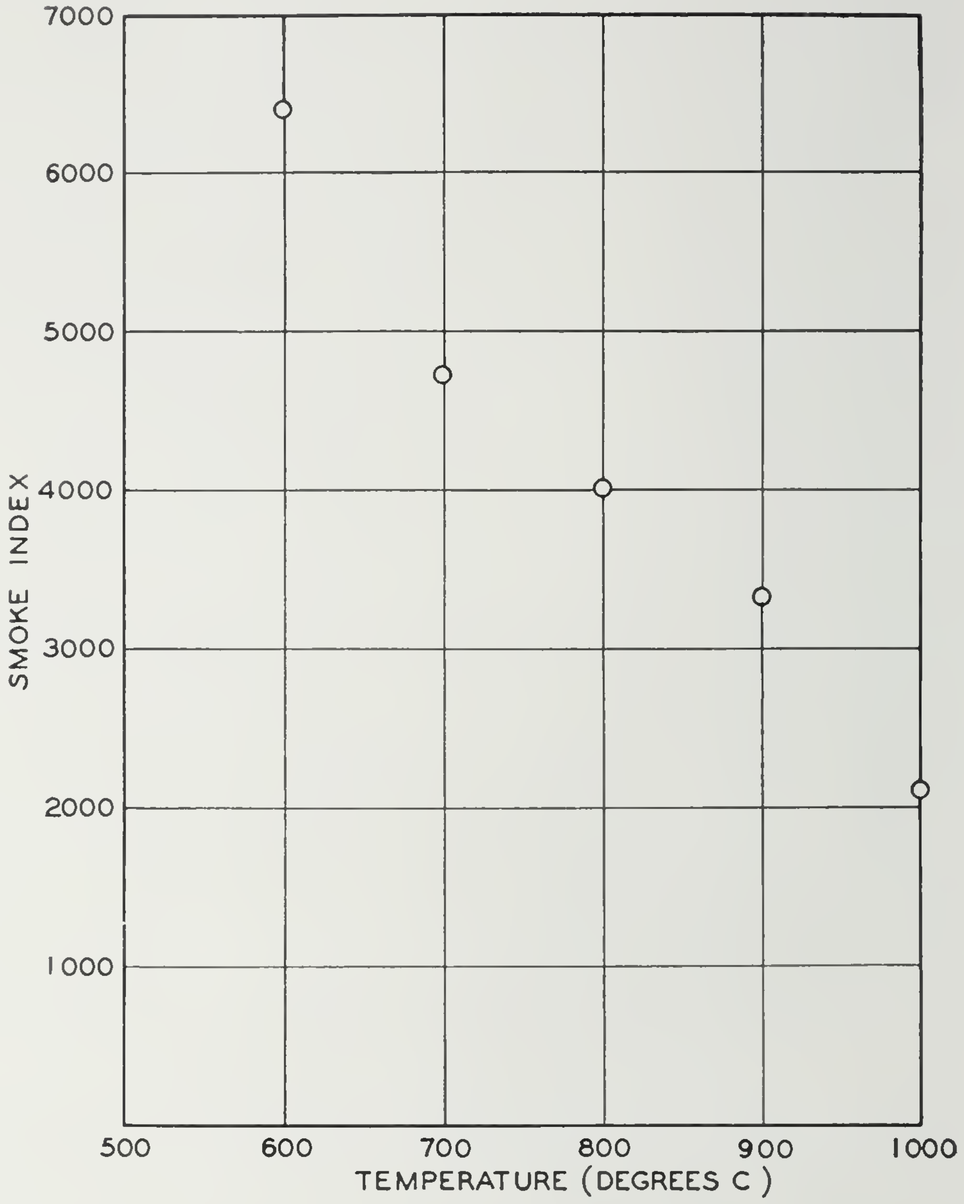

Fig. 14.—Effect of Temperature on Smoke Index.

Table 18.—Effect of Temperature on Smoke Index (Summary) (Air Supply—4 Cubic Feet per Minute)

(Data for Fig. 14)

Temperature °C.	Smoke indices				
	600°C.	700°C.	800°C.	900°C.	1000°C.
Test number—					
1	6740	4170	3470	3050	1630
2	6190	4870	4510	3730	3000
3	6080	3980	3760	2780	2030
4	6190	5220	3630	3670	1950
5	6320	4960	4120	3200	1430
6	6660	4960	3890	3800	2230
7	6560	4680	4080	3910	2110
8	6730	4190	3400	3380	2080
9	5980	4360	5150	3050	2750
10	6490	5700	3560	2490	2300
Average	6390	4710	3990	3310	2150

REPRODUCIBILITY OF SMOKE INDEX

A series of tests was made, using the preferred air supply of 4 cubic feet per minute and the preferred temperature of 600°C. in order to ascertain the degree of reproducibility of smoke index values. The individual results are shown in Table 19. It is seen that the per cent deviation from the average value varies from 0.9 to 6.3 per cent, with a mean deviation of 3.7 per cent.

The temperature of the furnace was maintained at 600±3°C., by means of a thermocouple and potentiometer. As noted previously, the temperature increases only about 3.0°C. due to the heat liberated by the coal sample.

The potential on the lamp fluctuates between 107 and 111 volts during the tests, but these fluctuations are rapid and therefore do not introduce an appreciable error.

The air supply remains constant to within a pressure difference of 2 mm. of mercury, which is equivalent to approximately 0.1 cubic foot per minute (see calibration curve for manometer, Fig. 8) for the rate of air flow used, namely 4 cubic feet per minute.

Also, there are additional errors due to temperature changes in the photoelectric cell, and of course no block of coal can provide two identical samples. But all these various errors are not cumulative and, therefore, the method has a maximum error of 6.3 per cent and an average error of 3.7 per cent for similar samples of coal.

TABLE 19.—REPRODUCIBILITY OF SMOKE INDICES (AIR SUPPLY—4 CUBIC FEET PER MINUTE)

Test number	Smoke index	Deviation from average	Per cent deviation from average
1	6740	+360	5.6
2	6190	—190	3.0
3	6080	—300	4.7
4	6190	—190	3.0
5	6320	—60	0.9
6	6660	+280	4.4
7	6560	+180	2.8
8	6730	+350	5.5
9	5980	—400	6.3
10	6490	+110	1.7
11	6240	—140	2.2
Average	6380	233	3.7

CHAPTER VI—APPLICATION OF SMOKE INDEX METHOD

The smoke index method was first developed as a means for comparing the amounts of smoke given off by impacted briquets (made without binder) and the natural coals from which the briquets were made. It has also been used in this laboratory to determine the relative smokiness of smokeless fuel briquets as compared with ordinary briquets and natural coals. Smokeless fuel briquets, as herein referred to, are briquets impacted without binder from partially volatilized bituminous coal. In this last connection, the smoke index method served admirably the purpose of indicating just when a smokeless fuel condition was reached, thus determining exactly how much volatile matter must be driven off before a smokeless fuel briquet is obtained. The smoke index method may be extended to compare the smokiness of two different types of briquets, of briquets and natural coals of all kinds, and of two different natural coals; in short, it can be used to compare the relative smokiness of any two kinds of fuel within limits. When the method is used merely for comparative purposes, the apparatus need only give comparative results since absolute values are not needed, the tests all being made in the same apparatus held under constant operating conditions, and the relative smokiness of the fuels thus being accurately determined.

However, the method need not be limited to one of comparison only. Such a method can be made suitable for determining the inherent smokiness of any fuel under certain controlled conditions and it was with this idea in mind that the series of smoke index tests on naphthalene was made. A standard material should be used for calibrating the apparatus if results are to be reproduced in other laboratories. When this is done there is no reason why the same smoke index of a fuel cannot be obtained in various laboratories.

With sets of apparatus giving reproducible results and with representative samples, the smoke index method affords the means of determining the smokiness of any fuel in terms of the amount of smoke given off per unit weight.

The smoke index method will give the relative smokiness of two different types of coal without actually burning large quantities of the two coals.

The use of the smoke index method is illustrated by the following detailed results on the smoke index of naturally occurring coals of various volatile matter content and that of Illinois coal fines processed to various volatile matter contents by the method herein described.

SMOKE INDEX OF THE NATURAL COALS

Will County coal.—The experimental data and computations on the smoke index of eight portions of a sample of Will County coal in the first series of tests are given in Table 20. The average analysis of this coal (Table 1, Part I of report) shows a content of 43.5 per cent volatile matter and 9.1 per cent moisture (partly air dried).

The smoke index values, computed as described above, ranged from 4330 to 6260, and averaged 5350. This variation in smoke index values appears to be due to the banded character of bituminous coals, banded ingredients varying in their respective smoke content. On account of the heterogeneous character of coal, therefore, the smoke index value is obtained by averaging the values from several determinations.

Approximately three months later a second series of six smoke index tests (Table 21) were made on remaining portions of the same sample of coal to determine the effect of storage. As shown by the table, the values ran lower, ranging from 3630 to 4730, and averaging 4220. These lower values may reflect a possible loss of moisture and volatile matter during storage.

Table 20.—Smoke Index Data on Will County (B) Coal (Series No. 1)

(Average Analysis of this Coal bed: Volatile Matter 43.5 Per Cent; Moisture 9.1 Per Cent Partly Air Dried)

Time (seconds)	Test Samples								
	1	2	3	4	5	6	7	8	
	Galvanometer deflections (*a*) (mm.)								
0	194	243	227	250	235	237	210	222	
5	195	242	227	248	233	235	207	224	
10	198	241	227	248	230	237	205	222	
15	191	240	227	250	228	233	205	223	
20	194	238	227	241	225	232	201	222	
25	193	237	204	246	224	226	197	219	
30	187	235	180	230	219	213	186	218	
35	184	230	160	220	206	186	179	214	
40	176	224	140	200	200	180	155	205	
45	165	216	120	200	180	155	140	183	
50	145	207	100	150	138	147	120	171	
55	115	199	80	130	110	136	105	175	
60	116	190	60	90	0	100	98	164	
65	119	175	47	66	20	92	77	128	
70	100	160	43	52	17	79	61	111	
75	85	142	36	36	30	75	58	110	
80	76	124	40	30	60	0	65	110	
85	53	120	66	30	60	57	60	80	
90	50	116	36	24	67	50	73	74	
95	47	111	34	30	77	50	82	57	

Table 20.—Concluded

Time (seconds)	Test Samples								
	1	2	3	4	5	6	7	8	
	Galvanometer deflections (*a*) (mm.)								
100	45	105	44	35	60	66	57	54	
105	64	98	44	16	90	69	50	90	
110	31	90	62	46	80	65	61	30	
115	79	85	69	21	80	67	60	30	
120	43	80	65	90	100	75	61	47	
125	35	85	93	45	90	78	35	60	
130	44	90	110	150	120	82	28	110	
135	57	78	112	100	130	85	36	105	
140	70	65	180	100	200	105	60	150	
145	80	80	200	150	190	150	105	205	
150	63	95	190	160	190	212	160	194	
155	74	101	196	250	200	188	180	199	
160	100	107	200	230	195	200	205	....	
165	130	114	200	235	195	195	184	....	
170	180	220	....	235	....	196	192	....	
175	185	220	....	....	....	....	....	....	
180	176	220	....	....	....	....	....	....	
Total	4239	5823	4246	4834	4679	4753	4158	4606	
Number readings	37	37	34	35	34	35	35	32	
A	114.6	157.4	124.9	138.1	137.6	135.8	118.8	143.9	
B	185.0	231.5	213.5	242.5	215.0	216.5	201.0	210.5	
X	38.1	32.0	41.4	43.1	36.0	37.3	40.9	31.6	
T	180	180	165	170	165	170	170	155	
S	6858	5760	6831	7327	5940	6341	6953	4898	Average smoke index
W	1.26	1.20	1.22	1.17	1.17	1.22	1.15	1.13	
I (smoke index)	5440	4800	5600	6260	5080	5200	6050	4330	5350

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (sec.)
S = total smoke = X × T.
W = weight of sample (grams).
I = smoke index = S/W.

a—The highest value of the galvanometer deflection represents no smoke and the lowest value, maximum smoke. See Part II of the Report for complete description of the smoke index method.

TABLE 21.—SMOKE INDEX DATA ON WILL COUNTY (B) COAL (SERIES NO. 2)

(Same Coal as Series No. 1 after 3 Months Storage)

Time (seconds)	Test samples						
	1	2	3	4	5	6	
	Galvanometer deflections						
0	213	203	204	202	212	204	
5	204	199	201	199	208	195	
10	197	193	191	194	202	175	
15	179	186	195	192	160	124	
20	169	159	166	180	115	103	
25	126	117	140	136	76	131	
30	119	112	126	160	80	65	
35	99	112	105	123	91	95	
40	79	117	79	159	80	87	
45	64	132	69	96	83	102	
50	46	70	86	66	69	107	
55	46	92	40	100	60	111	
60	41	63	69	70	77	124	
65	43	85	71	105	55	127	
70	26	83	58	52	72	111	
75	23	73	88	90	96	128	
80	23	72	111	72	76	122	
85	33	87	105	85	92	94	
90	130	72	123	115	82	93	
95	59	43	128	85	74	86	
100	109	85	102	125	115	132	
105	107	83	116	122	79	134	
110	139	78	106	119	148	138	
115	132	78	110	127	141	116	
120	122	92	122	115	169	138	
125	120	128	131	106	189	145	
130	143	128	107	134	....	165	
135	151	122	149	132	....	174	
140	161	115	172	136	....	186	
145	175	137	182	152	....	....	
150	196	180	179	191	....	....	
155	....	....	186	....	....	....	
Total	3474	3496	4017	3940	2901	3712	
Number readings	31	31	32	31	26	29	
A	112.1	112.8	125.5	127.1	111.6	128.0	
B	204.5	191.5	195.0	196.5	200.5	195.0	
X	45.2	41.1	35.6	35.3	44.3	34.4	
T	150	150	155	150	125	140	Average smoke index
S	6780	6165	5518	5295	5538	4816	
W	1.47	1.35	1.38	1.46	1.17	1.28	
I (smoke index)	4610	4570	4000	3630	4730	3760	4220

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time (sec.)
S = total smoke = X × T.
W = weight of sample (grams).
I = smoke index = S/W.

Washington County coal.—Table 22 gives the experimental data on Washington County coal. The smoke index values for nine tests ranged from 3890 to 5050 and averaged 4380. The character of this coal is approximately that indicated by the analysis of Washington County coal in Table 1 (Part I, p. 18). It contained 41.5 per cent volatile matter and 8.5 per cent moisture.

TABLE 22.—SMOKE INDEX DATA ON WASHINGTON COUNTY COAL

(Analysis of Sample: Volatile Matter 41.5 Per Cent; Moisture 8.5 Per Cent Partly Air Dried)

Time (seconds)	Test samples								
	1	2	3	4	5	6	7	8	9
	Galvanometer deflections (mm.)								
0......	220	226	210	196	223	184	200	218	188
5......	220	222	210	195	223	182	200	219	190
10......	218	223	210	198	223	185	198	219	188
15......	218	222	210	194	222	180	200	216	186
20......	215	218	208	155	220	182	197	214	184
25......	212	220	209	136	218	182	190	189	172
30......	195	213	190	120	212	168	186	185	125
35......	180	184	177	100	200	151	156	142	91
40......	171	181	180	65	190	146	125	122	110
45......	152	146	155	65	173	140	103	75	74
50......	139	142	140	20	169	118	96	79	64
55......	133	146	104	50	156	105	109	60	30
60......	127	119	66	56	117	95	80	51	4
65......	99	119	79	45	86	45	1	59	29
70......	90	101	35	82	94	30	30	56	25
75......	76	90	10	84	69	41	30	83	33
80......	95	75	17	52	101	46	59	9	33
85......	38	70	19	68	0	56	56	37	47
90......	38	65	25	70	50	62	54	39	35
95......	89	70	32	76	29	47	27	42	45
100......	47	30	32	70	57	67	90	29	35
105......	55	55	60	71	100	46	95	55	60
110......	123	51	54	81	41	79	81	56	50
115......	102	71	63	70	68	90	96	67	50
120......	82	96	85	54	70	99	90	70	80
125......	100	109	74	101	60	107	80	77	54
130......	115	120	99	119	95	124	101	77	87
135......	137	119	144	172	101	162	110	113	117
140......	204	131	150	155	105	144	115	124	159
145......	184	139	150	169	190	153	130	184	140
150......	190	154	151	173	184	150	145	165	146
155......	195	170	156	....	177	148	173	173	146
160......	....	207	158	....	184	152	159	172	150
165......	....	192	163	....	184	150	163	174	161
170......	....	199	....	....	190	150	160	175	153
175......	....	194	....	....	....	158	161	....	157
180......	....	190	....	....	....	....	163	....	....
185......	....	194	....	....	....	....	160	....	....

Table 22.—Concluded

Time (seconds)	Test samples									
	1	2	3	4	5	6	7	8	9	
	Galvanometer deflctions (mm.)									
190	....	196	....	....	....	....	160	....	....	
195	....	....	....	....	....	....	160	....	....	
200	....	....	....	....	....	....	173	....	....	
Total	4459	5669	4025	3262	4781	4324	5062	4025	3598	
Number readings	32	39	34	31	35	36	41	35	36	
A	139.3	145.4	118.4	105.2	136.6	120.1	123.5	115.0	99.9	
B	207.5	211.0	186.5	184.5	206.5	171.0	186.5	196.5	172.5	
X	32.9	31.1	36.5	43.0	33.8	29.8	33.8	41.5	42.1	
T	155	190	165	150	170	175	200	170	175	
S	5100	5909	6023	6450	5746	5215	6760	7055	7368	
W	1.31	1.38	1.45	1.55	1.34	1.31	1.40	1.47	1.46	Average smoke index
I (smoke index)	3890	4280	4150	4160	4290	3980	4810	4800	5050	4380

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = weight of sample (grams).
I = smoke index = S/W.

Franklin County coal.—Table 23 gives the experimental data on Franklin County coal. The smoke index values for seven tests ranged from 3200 to 3810 and averaged 3650. This coal is similar to that represented by the analysis of Franklin County coal in Table 1 (Part I of report). It contained approximately 33.8 per cent volatile matter and 8.7 per cent moisture.

Table 23.—Smoke Index Data on Franklin County (B) Coal
(Analysis of Sample: Volatile Matter 33.8 Per cent; Moisture 8.7 Per Cent)

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	
	Galvanometer deflections							
0	216	205	190	179	180	230	260	
5	213	202	188	178	178	228	250	
10	210	195	187	176	172	225	251	
15	208	194	188	176	171	215	253	
20	204	190	185	174	158	210	240	
25	195	175	180	163	152	197	225	
30	178	160	174	145	129	193	210	
35	160	142	160	130	119	179	205	
40	137	142	145	110	112	169	180	
45	125	115	135	104	101	156	165	
50	107	102	123	91	76	174	142	
55	90	90	119	81	73	50	120	
60	74	89	115	84	59	36	110	
65	70	100	10	35	90	58	30	
70	55	17	55	40	50	64	70	
75	50	47	40	40	35	76	55	
80	50	42	80	50	38	58	80	
85	55	55	65	45	54	64	105	
90	90	55	80	52	57	77	125	
95	60	85	89	49	59	115	120	
100	80	110	90	83	47	63	105	
105	120	130	92	104	57	74	140	
110	90	105	103	99	78	123	135	
115	150	130	108	114	86	128	165	
120	125	140	136	104	79	143	20	
125	120	190	128	117	106	165	105	
130	170	175	130	133	107	194	130	
135	177	180	130	142	127	195	142	
140	195	....	....	162	135	197	170	
145	....	....	170	157	135	197	230	
150	....	....	175	159	141	199	....	
155	....	....	....	....	137	....	....	
Total	3774	3562	3770	3476	3298	4452	4538	
Number readings	29	28	30	31	32	31	30	
A	130.1	127.2	125.7	112.1	103.1	143.6	151.3	
B	205.5	192.5	182.5	169.0	158.5	214.5	245.0	
X	36.7	33.9	31.1	33.7	35.0	33.1	38.2	
T	140	135	150	150	155	150	145	Average smoke index
S	5138	4577	4665	5055	5425	4965	5539	
W	1.35	1.25	1.30	1.37	1.42	1.55	1.46	
I (smoke index)	3810	3660	3590	3690	3820	3200	3790	3650

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time (seconds).
S = total smoke = X × T.
W = weight of sample (grams).
I = smoke index = S/W.

West Virginia coals.—Table 24 gives the experimental data on West Virginia (A) and West Virginia (B), Beckley bed, and West Virginia (C), Jewell bed. For West Virginia (A) the smoke index values for four tests ranged from 1540 to 2070 and averaged 1770; for West Virginia (B) the values for four tests ranged from 1580 to 2200 and averaged 1820; and for West Virginia (C) the values for three tests ranged from 2550 to 2970 and averaged 2720. According to Black's Directory, Fourth Edition, 1935, the coals contain 16.2, 17.7 and 22.5 per cent volatile matter, and 0.7, 0.0, and 1.4 per cent moisture respectively.

Table 24.—Smoke Index of West Virginia Coals

Time (seconds)	Sample A (Beckley Co.) (Volatile matter 16.2 per cent) "as received"				Sample B (Raleigh Co.) (Volatile matter 17.7 per cent) "as received"				Sample C (Jewell Co.) (Volatile matter 22.5 per cent) "as received"		
	Test samples										
	1	2	1	2	1	2	1	2	1	2	3
	Galvanometer deflections (mm.)										
0	181	184	173	188	187	184	193	186	185	187	188
5	181	184	173	188	187	184	192	186	184	187	188
10	181	184	173	188	188	184	192	186	184	185	187
15	181	184	173	187	188	183	193	186	183	186	186
20	181	184	173	188	187	183	193	185	179	185	187
25	181	183	172	188	187	184	193	186	172	185	184
30	181	181	171	187	186	183	192	186	162	182	177
35	179	179	167	187	186	182	190	184	148	176	173
40	179	175	162	185	184	182	189	183	138	166	166
45	178	169	153	182	180	181	186	180	133	159	166
50	172	162	154	176	173	179	183	172	119	153	163
55	166	161	151	166	171	176	178	163	113	141	148
60	159	152	142	156	165	172	171	138	106	141	149
65	150	149	134	143	153	168	161	132	99	124	92
70	137	156	123	139	141	161	156	138	93	109	83
75	134	131	116	134	129	156	148	164	91	67	83
80	134	123	132	128	116	146	141	159	91	70	84
85	132	139	130	123	107	139	132	172	103	70	84
90	116	136	130	116	108	145	116	177	76	69	87
95	137	133	132	115	139	103	103	154	79	76	98
100	142	114	142	106	126	98	97	134	82	78	109
105	146	98	147	111	118	106	120	121	77	84	123
110	151	76	147	141	115	115	112	132	81	87	131
115	149	101	155	143	98	102	116	161	86	93	136
120	105	109	163	156	105	98	129	181	92	99	143
125	83	117	143	168	117	130	148	184	102	103	147
130	104	114	96	175	123	120	160	......	108	113	154
135	108	126	110	177	129	125	175	......	118	119	161
140	122	132	118	180	133	123	182	......	126	122	166

Table 24.—Concluded

Time (seconds)	Sample A (Beckley Co.) (Volatile matter 16.2 per cent) "as received"				Sample B (Raleigh Co.) (Volatile matter 17.7 per cent) "as received"				Sample C (Jewell Co.) (Volatile matter 22.5 per cent) "as received"		
	Test samples										
	1	2	1	2	1	2	1	2	1	2	3
	Galvanometer deflections (mm.)										
145.........	131	147	132	181	142	130	186	......	132	131	171
150.........	134	172	113	183	151	137	......	......	138	135	177
155.........	136	174	131	......	162	92	......	......	143	142	178
160.........	139	......	152	......	181	105	......	......	145	148	179
165.........	141	......	161	......	184	130	......	......	150	159	......
170.........	143	......	169	......	......	151	......	......	153	165	......
175.........	153	......	170	......	......	174	......	......	164	170	......
180.........	167	......	171	......	......	......	......	......	166	174	......
185.........	168	......	......	......	......	......	......	......	167	......	......
190.........	......	......	......	......	......	......	......	......	169	......	......
Total....	5662	4729	5454	4985	5146	5311	4827	4330	5037	4940	4848
Number readings.....	38	32	37	31	34	36	30	26	39	37	33
A.........	149.0	147.8	147.4	160.8	151.4	147.5	160.9	166.5	129.2	133.5	146.9
B.........	174.5	179.0	172.0	185.5	185.5	179.0	189.5	185.0	177.0	180.5	183.5
X.........	14.6	17.4	14.3	13.3	18.4	17.6	15.1	10.0	27.0	26.0	19.9
T.........	185	155	180	150	165	175	145	125	190	180	160
S.........	2701	2697	2574	1995	3036	3080	2190	1250	5130	4680	3184
W.........	1.48	1.30	1.67	1.21	1.38	1.60	1.39	0.79	1.73	1.78	1.25
I (smoke index)...	1830	2070	1540	1650	2200	1930	1580	1580	2970	2630	2550
	Average=1770				Average=1820				Average=2720		

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.

T = total time (seconds).
S = total smoke = X × T.
W = weight of sample (grams).
I = smoke index = S/W.

RELATIONSHIP BETWEEN SMOKE CONTENT AND VOLATILE MATTER OF NATURAL COALS

The foregoing results are summarized in Table 25 and also in a graph (Fig. 15) in which the average smoke index is plotted against the percentage of volatile matter, an inspection of which indicates an approximation of a straight-line relationship for the seven coals tested.

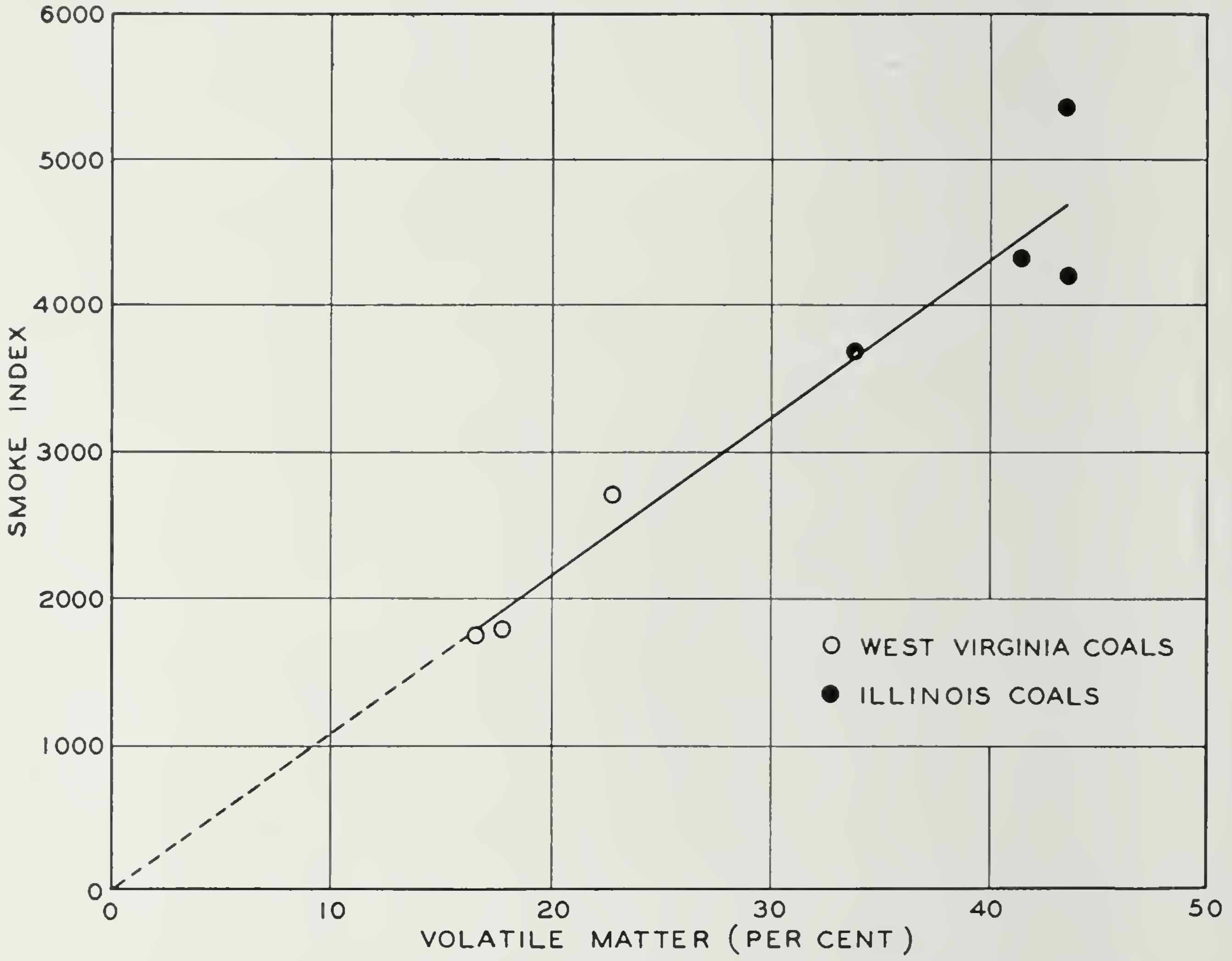

Fig. 15.—Effect of the Amount of Naturally Occurring Volatile Matter on the Smoke Index of Coal.

Table 25.—Effect of Amount of Naturally Occurring Volatile Matter on Smoke Index of Coal

(Data for Fig. 15)

Location	Bed	Moisture (*a*) (per cent)	Volatile matter (*a*) (per cent)	Average smoke index
Will County (Series No. 1)	2	9.1	43.5	5350
Will County (Series No. 2)	2	(*b*)	(*b*)	4220
Washington County	6	8.5	41.5	4380
Franklin County	6	8.7	33.8	3650
West Virginia (A)	Beckley	0.7	16.2	1770
West Virginia (B)	Beckley	0.0	17.7	1820
West Virginia (C)	Jewell	1.4	22.5	2720

(*a*) As received basis.
(*b*) Same coal as used in Will County Series No. 1 after three months storage.

CALCULATION OF VOLATILE MATTER IN PARTIALLY VOLATILIZED COALS

Analyses of coal heated from 275°C. to about 500°C. indicate that losses in weight are due, as would be expected, to loss in volatile matter (Table 26). In the present studies this loss in weight is therefore used directly as a means of determining the volatile matter content of the partially volatilized coal according to the following formula:

$$VM_{X} = \frac{VM_{D} - L_{D}}{100 - L_{D}}$$

where VM_{D} is the per cent volatile matter in the raw coal (dry basis) and L_{D} is the per cent loss in weight above 275°C. or on the dry basis.

This calculation may be illustrated by an example taken from values in Table 26. In order to calculate the per cent volatile matter in sample C-737 from the volatile matter in sample C-738, the above equation becomes as follows:

$$VM_{D} = \frac{43.9 - 13.4}{100 - 13.4} = 35.3$$

Removal of volatile matter will of course produce a corresponding increase in fixed carbon and ash according to the formula

$$\frac{\text{Fixed carbon (or ash)}_{T = L}}{100 - L_{D}} = \text{Fixed carbon (or ash)}_{T = H}$$

where $T = L$ is the per cent at a certain temperature and $T = H$ is that at a higher temperature.

The volatile matter lost probably will include some sulfur, hence the amount of sulfur present in the coal at increasingly higher temperatures above 275°C., can be known only by analysis. The data in Table 26 indicate that for these samples more than 25 per cent of the sulfur is volatilized between 275°C. and 530°C.

Table 26.—Analyses of Briquets Volatilized to Various Stages of Volatilization (*a*)

Analysis No. (*b*)	County	Bed	Oven temper-ature (*c*) (°C.)	Weight loss (per cent)	Volatile matter (per cent)		Ash (per cent)		Fixed carbon (per cent)		Total sulfur (per cent)		B. t. u.
					Anal.	Calc.	Anal.	Calc.	Anal.	Calc.	Anal.	Calc.	
C-738	Will	2	275	0.0	43.9	43.9	5.3	5.3	50.8	50.8	3.4	3.4	13299
C-737	Will	2	500	13.4	35.5	35.3	6.0	6.1	58.6	58.6	3.1	3.9	13297
C-736	Will	2	515	15.9	32.7	33.3	6.9	6.3	60.4	60.4	3.1	4.0	13250
C-735	Will	2	530	19.0	31.0	30.7	6.3	6.5	62.6	62.8	3.3	4.2	13288
C-740	Franklin	6	275	0.0	35.9	35.9	7.1	7.1	57.0	57.0	1.1	1.1	13246
C-884	Franklin	6	450	5.6	32.0	32.1	7.6	7.5	60.4	60.4	1.0	1.2	13132
C-885	Franklin	6	475	8.8	30.2	29.7	7.4	7.8	62.4	62.5	1.0	1.2	13188
C-886	Franklin	6	500	12.8	26.3	26.5	7.8	8.1	65.4	65.4	1.0	1.3	13098
C-887	Franklin	6	525	15.7	24.4	23.9	8.1	8.4	67.5	67.7	0.9	1.3	12981

(*a*) Analyses made in 1934, all values on moisture-free basis.

(*b*) C-738, 737, 736, and 735 are portions of one Will County sample; C-740, 884, 885, 886, and 887 are likewise portions of one Franklin County sample.

(*c*) Volatilization period of 10 minutes.

SMOKE INDEX OF BRIQUETS MADE BY IMPACT FROM PARTIALLY VOLATILIZED COALS

The samples of coal from Will and Franklin counties were volatilized to various degrees, and briquets without artificial binder were made by the impact process in order to determine the smoke indices of the partially volatilized coal.

The minus 4-mesh coal was first heated for 10 minutes at a temperature of 275°C., the loss of weight being assigned to moisture loss; subsequent losses in weight at higher temperatures were assigned to volatile matter, and from such loss the volatile matter remaining in the coal was calculated, using the formula given above.

Will County briquets.—Separate portions of the sample of Will County coal were preheated for 10 minutes, each at a different temperature. These products were then briquetted and from four to eight duplicate smoke index tests were made on 1-cm. cubes cut from the briquets.

The data are shown in tabular form as follows: Table 27 for briquetted coal preheated at 250°C. (coal temperature), retaining its original 43.9 per cent volatile matter; Table 28 for the product partially volatilized at 477°C. and containing 39.3 per cent volatile matter; Table 29 for the product partially volatilized at 485°C. and containing 35.8 per cent volatile matter; Table 30, for the product partially volatilized at 505°C. and containing 31.9 per cent volatile matter; Table 31, for the product partially volatilized at 515°C. and containing 24.3 per cent volatile matter; and Table 32, for the product partially volatilized at 535°C. and containing 16.4 per cent volatile matter.

The data are averaged and summarized in Table 6 (Part I of report), including the individual smoke indices with the exception of those of the sample prevolatilized at 477°C. shown in Table 28. Apparently volatilization was not uniform throughout this sample, possibly due to the greater volatilization of the smaller grains of coal.

In figure 5 (Part I of report) the smoke index is plotted against the volatile matter content of the partially prevolatilized briquets. This curve indicates a linear relationship for Will County coal for briquets volatilized at temperatures of 250°, 477°, 485°, and 505°C. Those volatilized at temperatures of 515° and 535°C. possess a smoke index of less than 150.

Table 27.—Smoke Index of Nonvolatilized Will County Briquet Containing 43.9 Per Cent Volatile Matter at Temperature of 250°C. for 10 Minutes

Time (seconds)	Test samples						
	1	2	3	4	5	6	7
	Galvanometer deflections (mm.)						
0	201	219	203	230	210	212	204
5	199	214	195	229	206	200	202
10	191	216	186	222	185	181	202
15	171	215	183	150	144	143	200
20	136	206	130	98	125	125	199
25	112	186	84	115	104	110	179
30	90	164	79	92	106	134	147
35	91	151	63	86	64	71	113
40	89	90	80	103	56	97	98
45	86	66	45	80	76	102	92
50	78	90	71	76	70	100	89
55	79	71	71	103	79	99	82
60	90	81	79	82	91	110	95
65	100	82	85	73	95	107	110
70	111	92	94	103	96	98	89
75	101	92	100	98	99	104	96
80	115	96	95	103	100	106	120
85	100	101	85	81	115	96	133
90	100	84	100	86	113	104	136
95	100	85	102	105	130	114	147
100	100	84	112	110	91	114	142
105	105	93	115	129	109	119	153
110	115	99	131	140	105	150	172
115	124	86	138	176	163	157	181
120	139	104	86	170	....	170	198
125	155	121	110	177	182	183	....
130	160	140	143	191	....	192	....
135	175	161	155	....	....	189	....
140	....	169	174	....	....	188	....
145	....	187	178	....	....	191	....
150	....	188	173	....	....	193	....
155	....	195	174	....	....	....	....
160	....	....	177	....	....	....	....
165	....	....	178	....	....	....	....
170	....	....	179	....	....	....	....
Total	3413	4228	4353	3408	2914	4259	3579
Number of readings	28	32	35	27	25	31	25
A	121.9	132.1	124.4	126.2	116.6	137.4	143.2
B	188.0	207.0	191.0	210.5	196.0	202.5	201.0
X	35.2	36.2	34.9	40.0	40.5	32.1	28.8
T	135	155	170	130	125	150	120
S	4752	5611	5933	5200	5063	4815	3456
W	1.47	1.53	1.45	1.37	1.30	1.39	1.03
I (smoke index)	3230	3670	4090	3800	3890	3460	3360

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 28.—Smoke Index of Will County Briquets Volatilized to 39.3 Per Cent Volatile Matter at Temperature of 477°C. for 10 Minutes

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	236	224	224	214	210	215	206	212
5	233	221	222	212	209	209	202	208
10	224	221	218	208	208	208	195	210
15	199	218	174	180	207	202	174	206
20	152	212	159	134	204	178	169	190
25	151	188	141	100	194	139	157	169
30	119	175	115	112	191	129	149	162
35	124	150	130	81	174	105	140	139
40	122	128	111	108	165	96	143	145
45	125	123	123	95	155	129	129	122
50	123	122	122	98	152	96	148	134
55	126	118	130	99	130	115	135	139
60	115	110	129	93	106	115	146	134
65	121	145	144	88	113	113	126	151
70	110	203	129	107	109	119	137	139
75	109	164	124	113	117	116	133	126
80	126	166	145	101	113	122	141	135
85	129	170	161	97	125	134	148	132
90	133	160	105	106	130	132	151	139
95	130	154	181	109	127	118	163	135
100	123	173	159	100	143	113	173	143
105	132	167	165	110	152	142	177	167
110	174	198	193	125	168	149	198	173
115	195	205	188	155	182	159	202	185
120	218	218	205	158	203	179	....	187
125	212	216	207	175	....	191	....	195
130	213	222	206	194	....	198	....	201
135	215	....	207	195	....	....	....	203
140	221	....	207	196	....	....	....	202
145	216	....	209	....	....	....	....	204
150	218	....	210	....	....	....	....	....
155	220	....	....	....	....	....	....	....
160	222	....	....	....	....	....	....	....
Total	5487	4771	5143	3863	3987	3921	3842	4987
Number readings	33	27	31	29	25	27	24	30
A	166.3	176.7	165.9	133.2	159.5	145.2	160.1	166.2
B	229.0	223.0	217.0	205.0	206.5	206.5	204.0	208.0
X	27.4	20.8	23.5	35.0	22.8	29.7	21.5	20.1
T	160	130	150	140	120	130	115	145
S	4384	2704	3525	4900	2736	3861	2473	2915
W	1.24	1.44	1.05	1.44	1.35	1.27	1.43	1.53
I (smoke index)	3540	1880	3360	3400	2030	3040	1730	1910

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

TABLE 29.—SMOKE INDEX OF EIGHT 1-CM. CUBES CUT FROM A WILL COUNTY BRIQUET VOLATILIZED TO 35.8 PER CENT VOLATILE MATTER AT TEMPERATURE OF 485°C. FOR 10 MINUTES.

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	222	221	217	215	213	207	211	206
5	217	219	216	208	209	....	204	203
10	202	219	206	214	203	205	202	203
15	189	215	196	208	200	196	191	197
20	178	199	189	201	183	191	184	188
25	157	180	172	181	167	174	171	173
30	156	165	159	165	156	160	156	167
35	151	142	154	151	135	151	145	156
40	140	141	156	143	142	136	121	137
45	155	143	146	151	131	136	132	143
50	141	157	144	141	139	128	118	134
55	160	156	147	137	123	130	127	123
60	147	178	150	126	130	120	125	136
65	167	166	161	148	117	123	126	124
70	164	166	158	135	127	137	113	126
75	162	191	156	143	140	132	143	139
80	168	177	171	148	130	138	135	132
85	170	190	162	147	147	145	146	143
90	174	184	164	149	154	148	151	155
95	186	194	174	166	170	151	163	166
100	187	196	179	155	176	162	171	177
105	203	206	195	172	192	168	166	195
110	214	213	195	180	202	183	173	196
115	217	217	199	184	205	191	183	200
120	221	....	209	201	208	198	197	....
125	....	....	217	210	....	207	206	203
Total	4448	4435	4592	4379	4099	4017	4160	4122
Number readings	25	24	26	26	25	25	26	25
A	177.9	184.8	176.6	168.4	164.0	160.7	160.0	164.9
B	221.5	219.0	217.0	212.5	210.5	207.0	208.5	204.5
X	19.7	15.6	18.6	20.8	22.1	22.4	23.3	19.4
T	120	115	125	125	125	125	125	125
S	2364	1794	2325	2600	2652	2800	2913	2425
W	1.44	1.13	1.58	1.38	1.34	1.54	1.52	1.33
I (smoke index)	1640	1590	1470	1880	1980	1820	1920	1820

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$.
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 30.—Smoke Index of Will County Briquets Volatilized to 31.9 Per Cent Volatile Matter at Temperature of 505°C. for 10 Minutes

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	231	231	237	241	241	255	240	237
5	229	226	234	234	240	249	239	233
10	223	222	235	239	233	250	236	231
15	224	213	233	236	234	246	233	236
20	220	205	230	233	226	249	233	232
25	217	194	226	231	229	237	233	232
30	211	186	221	229	221	242	226	224
35	210	187	216	229	222	234	227	223
40	207	177	218	225	219	231	225	223
45	215	183	217	225	213	226	222	221
50	206	181	215	222	220	240	227	219
55	224	184	210	226	209	233	227	214
60	216	190	213	218	210	226	218	216
65	217	187	210	230	204	232	217	212
70	218	197	206	227	208	224	215	216
75	221	197	212	232	205	223	218	213
80	222	224	210	233	211	219	213	218
85	225	225	209	....	202	223	226	213
90	228	228	217	239	179	231	232	213
95	229	....	223	242	184	233	235	217
100	....	....	231	....	189	249	239	225
105	....	....	233	....	194	252	....	233
110	....	....	234	....	212	....	....	233
115	....	....	235	....	232	....	....	234
120	....	....	....	....	243	....	....	237
Total	4393	3837	5325	4391	5380	5204	4781	5605
Number readings	20	19	24	19	25	22	21	25
A	219.7	201.9	221.9	231.1	215.2	236.5	227.7	224.2
B	230.0	229.5	236.0	241.5	242.0	253.5	239.5	237.0
X	4.48	12.0	5.97	4.31	11.1	6.71	4.93	5.40
T	95	90	115	95	120	105	100	125
S	426	1080	687	409	1332	705	493	675
W	1.62	1.39	1.25	1.50	1.53	1.34	1.52	1.42
I (smoke index)	263	777	550	273	871	526	324	475

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 31.—Smoke Index of Will County Briquets Volatilized to 24.3 Per Cent Volatile Matter at Temperature of 515°C. for 10 Minutes

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	227	224	230	229	230	238	233	232
5	225	221	226	227	229	235	230	228
10	223	221	224	226	229	235	227	229
15	216	221	227	225	223	234	228	226
20	216	219	227	227	220	234	227	205
25	214	216	226	229	217	236	227	208
30	215	213	221	227	213	236	224	213
35	215	217	221	227	206	236	227	215
40	213	219	223	227	207	234	227	221
45	215	219	220	226	213	230	229	224
50	220	219	221	227	218	234	226	234
55	196	220	220	221	225	233	229	229
60	218	223	226	227	225	230	233	229
65	209	226	226	218	....	238	229	233
70	217	....	225	222	....	....	234	....
75	219	....	224	218	228	....	....	....
80	226	....	230	221	....	....	....	....
85	220	....	....	220	....	....	....	....
90	228	....	....	225	....	....	....	....
Total	4132	3078	3817	4269	3083	3283	3430	3126
Number readings	19	14	17	19	14	14	15	14
A	217.5	219.9	224.5	224.7	220.2	234.5	228.7	223.3
B	227.5	225.0	230.0	227.0	229.0	238.0	233.5	232.5
X	4.39	2.27	2.39	1.01	3.84	1.47	2.06	3.96
T	90	65	80	90	75	65	70	65
S	395	148	191	90.9	288	95.6	144	257
W	1.61	1.51	1.50	1.42	1.57	1.44	1.38	1.08
I (smoke index)	245	98	127	64	183	66	104	238

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 32.—Smoke Index of Will County Briquets Volatilized to 16.4 Per Cent Volatile Matter at Temperature of 535°C. for 10 Minutes

Time (seconds)	Test samples			
	1	2	3	4
	Galvanometer deflections (mm.)			
0	222	225	224	229
5	217	223	221	224
10	217	220	216	224
15	217	220	209	225
20	219	221	204	224
25	217	215	209	223
30	214	216	210	224
35	211	218	215	223
40	210	214	216	221
45	211	218	218	223
50	209	222	221	223
55	222	221	223	223
60	210	224	....	222
65	210	....	....	224
70	215	....	....	226
75	220	....	....	226
80	221	....	....	226
85	....	....	....	225
90	....	....	....	224
95	....	....	....	220
100	....	....	....	223
105	....	....	....	226
Total	3662	2857	2586	4928
Number readings	17	13	12	22
A	215.4	219.8	215.5	224.0
B	221.5	224.5	223.5	227.5
X	2.75	2.09	3.58	1.54
T	80	60	55	105
S	220	125	197	162
W	1.38	1.30	1.41	0.86
I (smoke index)	159	96	140	188

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Franklin County briquets.—A similar series of tests was made for Franklin County coal. These smoke index results are shown in Tables 33, 34, 35, 36, and 37 for the products partially volatilized at temperatures of 250°, 450°, 465°, 480°, and 495°C., and containing 35.9, 33.1, 30.9, 28.5, and 23.6 per cent volatile matter, respectively. The same data are averaged and summarized in Table 7 (Part I of report).

In figure 6 (Part I of report) the smoke index is plotted against the volatile matter content for Franklin County coal in a manner similar to that in figure 5 (Part I of report) for Will County coal. This curve likewise indicates a linear relationship between volatile matter content and smoke index for Franklin County coal.

TABLE 33.—SMOKE INDEX OF NONVOLATILIZED FRANKLIN COUNTY BRIQUETS CONTAINING 35.9 PER CENT VOLATILE MATTER HEATED AT TEMPERATURE OF 250°C. FOR 10 MINUTES

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	170	163	171	163	165	159	157	156
5	166	161	163	162	161	158	155	154
10	166	156	151	160	151	156	154	153
15	166	154	136	152	132	151	149	152
20	167	146	121	136	116	141	135	153
25	163	130	114	115	100	132	117	151
30	156	120	112	102	85	116	107	140
35	144	72	120	84	92	109	92	123
40	147	102	105	82	83	104	85	103
45	139	96	115	84	91	117	77	95
50	132	99	109	101	92	62	68	82
55	91	97	113	83	85	89	67	96
60	105	93	108	102	117	87	95	81
65	100	100	108	90	100	87	105	98
70	106	98	106	98	97	94	82	91
75	102	97	109	97	101	85	98	98
80	106	98	109	97	106	92	103	94
85	109	110	118	100	105	83	114	102
90	111	111	117	93	101	84	119	102
95	111	99	109	93	108	86	118	107
100	109	110	102	102	109	99	128	105
105	112	108	120	113	106	104	130	107
110	107	128	129	124	114	126	141	96
115	101	138	136	136	131	128	152	105
120	106	145	148	149	140	143	148	134
125	110	144	159	....	151	148	150	137
130	126	145	162	....	156	147	152	144
135	135	145	....	....	....	148	....	....
140	146	147	....	....	....	151	....	....
145	161	148	....	....	....	....	....	....
150	157	....	....	....	....	....	....	....
155	157	....	....	....	....	....	....	....
160	158	....	....	....	....	....	....	....
165	159	....	....	....	....	....	....	....
Total	4501	3660	3370	2818	3095	3386	3198	3159
Number readings	34	30	27	25	27	29	27	27
A	132.4	122.0	124.8	112.7	114.6	116.8	118.4	117.0
B	164.5	155.5	166.5	156.0	160.5	155.0	154.5	150.0
X	19.5	21.5	25.0	27.8	28.6	24.6	23.4	22.0
T	165	145	130	120	130	140	130	130
S	3218	3118	3250	3336	3718	3444	3042	2860
W	1.30	1.30	1.31	1.25	1.37	1.27	1.08	1.17
I (smoke index)	2480	2400	2480	2670	2710	2710	2820	2440

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 34.—Smoke Index of Franklin County Briquets Volatilized to 33.1 Per Cent Volatile Matter at a Temperature of 450°C. for 10 Minutes

Time (seconds)	Test samples						
	1	2	3	4	5	6	7
	Galvanometer deflections (mm.)						
0	159	155	155	154	153	157	158
5	157	154	154	153	148	154	155
10	153	152	143	149	139	147	155
15	145	142	127	138	122	130	149
20	131	125	106	124	113	121	152
25	118	103	101	105	95	105	147
30	109	96	83	101	86	90	132
35	98	88	78	98	76	102	120
40	97	95	100	97	76	91	123
45	85	90	85	110	120	95	97
50	79	89	80	90	95	90	84
55	99	117	89	83	96	87	127
60	119	95	85	94	99	88	105
65	106	97	89	93	88	96	119
70	113	102	85	97	88	90	119
75	106	101	88	113	96	97	123
80	109	108	89	120	105	108	124
85	103	108	99	140	118	105	123
90	105	111	107	143	134	129	125
95	107	113	116	149	143	147	129
100	112	126	107	151	152	159	132
105	112	128	121	149	150	157	138
110	118	141	116	150	....	....	145
115	131	147	148	151	....	....	152
120	136	151	150	....	....	....	153
125	150	152	149	....	....	....	155
130	154	....	155	....	....	....	....
135	....	....	152	....	....	....	....
140	....	....	153	....	....	....	....
Total	3211	3086	3210	2952	2492	2545	3441
Number readings	27	26	29	24	22	22	26
A	118.9	118.7	110.7	123.0	113.3	115.7	132.3
B	156.5	153.5	154.0	152.5	151.5	157.0	156.5
X	24.0	22.7	28.1	19.3	25.2	26.3	15.5
T	130	125	140	115	105	105	125
S	3120	2838	3934	2220	2646	2762	1938
W	1.47	1.46	1.58	1.06	1.15	1.07	1.20
I (smoke index)	2120	1940	2490	2090	2300	2580	1620

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 35.—Smoke Index of Franklin County Briquets Volatilized to 30.9 Per Cent Volatile Matter at a Temperature of 465°C. for 10 Minutes

Time (seconds)	Test samples 1	2	3	4	5	6	7
	Galvanometer deflections (mm.)						
0	160	160	161	159	160	161	158
5	158	156	159	156	159	160	153
10	156	151	156	150	159	159	146
15	154	143	158	140	158	159	139
20	144	137	154	126	155	156	127
25	141	128	152	121	142	149	115
30	120	124	142	106	136	142	101
35	111	113	129	101	125	130	93
40	98	115	116	103	98	103	95
45	95	103	100	95	95	123	82
50	149	92	104	90	91	113	100
55	123	97	96	91	95	117	135
60	134	87	96	86	121	113	111
65	133	96	126	93	109	119	121
70	132	93	120	95	116	109	118
75	138	95	116	104	122	121	116
80	141	104	116	108	129	117	125
85	146	90	116	112	128	119	125
90	152	120	126	125	136	133	122
95	159	140	134	136	142	133	133
100	....	132	134	146	152	146	140
105	....	143	157	151	158	157	145
110	....	147	....	155	159	....	154
115	....	151	....	158	....	....	156
120	....	159	....	159	....	....	....
Total	2744	3076	2868	3066	3045	2939	3010
Number readings	20	25	22	25	23	22	24
A	137.2	123.0	130.4	122.6	132.4	133.6	125.4
B	159.5	159.5	159.0	159.0	159.5	159.0	157.0
X	14.0	22.9	18.0	22.9	17.0	16.0	20.1
T	95	120	105	120	110	105	115
S	1330	2748	1890	2748	1870	1680	2312
W	1.17	1.50	1.05	1.44	1.13	1.30	1.45
I (smoke index)	1140	1830	1800	1910	1650	1290	1590

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) $= \frac{B - A}{B} \times 100$
T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 36.—Smoke Index of Franklin County Briquets Volatilized to 28.5 Per Cent Volatile Matter at a Temperature of 480°C. for 10 Minutes

Time (seconds)	Test samples						
	1	2	3	4	5	6	7
	Galvanometer deflections (mm.)						
0	156	157	165	162	163	162	160
5	153	154	164	161	161	161	157
10	154	155	164	159	159	159	158
15	156	154	161	154	160	152	154
20	154	152	155	146	161	140	146
25	153	155	147	139	157	126	137
30	149	152	147	140	150	113	126
35	143	149	126	121	137	110	119
40	136	144	134	127	129	103	115
45	129	137	124	122	124	99	115
50	126	129	122	119	125	113	105
55	127	126	121	116	135	109	107
60	117	119	125	110	127	110	124
65	122	115	140	115	133	119	123
70	111	107	128	112	131	128	116
75	116	111	141	118	131	123	125
80	140	98	144	118	134	129	128
85	149	108	151	122	138	138	130
90	140	113	160	132	142	140	133
95	147	106	163	140	144	152	140
100	151	110	....	151	144	161	147
105	153	113	....	157	149	158	151
110	157	120	....	158	153	....	156
115	....	128	....	159	158	....	....
120	....	137	....	160	160	....	....
125	....	148	....	....	....	....	....
130	....	156	....	....	....	....	....
135	....	154	....	....	....	....	....
Total	3239	3707	2882	3418	3605	2905	3072
Number readings	23	28	20	25	25	22	23
A	140.8	132.4	144.1	136.7	144.2	132.0	133.6
B	156.5	155.5	164.0	161.0	161.5	160.0	158.0
X	10.0	14.9	12.1	15.1	10.7	17.5	15.4
T	110	135	95	120	120	105	110
S	1100	2012	1150	1812	1284	1838	1694
W	1.15	1.27	1.23	1.38	1.37	1.14	1.39
I (smoke index)	956	1580	934	1310	937	1610	1220

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

Table 37.—Smoke Index of Franklin County Briquets Volatilized to 23.6 Per Cent Volatile Matter at a Temperature of 495°C. for 10 Minutes

Time (seconds)	Test samples							
	1	2	3	4	5	6	7	8
	Galvanometer deflections (mm.)							
0	160	160	161	161	160	159	169	168
5	159	156	159	159	157	157	165	167
10	157	156	156	155	158	158	166	166
15	156	157	159	154	158	157	168	165
20	155	157	159	148	158	156	166	163
25	156	157	156	147	160	154	166	156
30	155	152	157	145	159	149	164	155
35	153	156	153	143	159	146	162	150
40	153	158	153	138	160	143	159	145
45	155	158	155	141	159	142	159	141
50	153	159	155	145	159	142	168	137
55	153	160	155	144	158	138	161	146
60	152	161	154	144	161	138	158	147
65	154	....	157	....	....	144	161	141
70	156	....	156	157	....	139	165	146
75	158	....	155	159	....	142	168	167
80	158	....	159	161	....	138	....	161
85	160	....	161	....	....	148	....	165
90	....	....	....	....	....	147	....	168
95	....	....	....	....	....	162	....	....
100	....	....	....	....	....	159	....	....
Total	2803	2047	2820	2401	2066	3118	2625	2954
Number readings	18	13	18	16	13	21	16	19
A	155.7	157.5	156.7	150.1	158.9	148.5	164.1	155.5
B	160.0	160.5	161.0	161.0	160.5	159.0	168.5	168.0
X	2.69	1.87	2.67	6.77	1.00	6.60	2.61	7.44
T	85	60	85	80	60	100	75	90
S	228.7	112.2	227.0	541.6	60.0	660.0	195.8	669.6
W	1.31	1.30	1.29	1.31	1.29	1.47	1.15	1.40
I (smoke index)	175	86	176	414	47	449	170	479

A = average deflection.
B = average of initial and final deflections.
X = average smoke density (percentage) = $\frac{B - A}{B} \times 100$

T = total time (seconds).
S = total smoke = X × T.
W = wt. of sample (grams).
I = smoke index = S/W.

RELATIONSHIP BETWEEN SMOKE INDEX AND VOLATILE MATTER CONTENT OF BRIQUETS MADE BY IMPACT FROM PARTIALLY VOLATILIZED COALS

For both naturally occurring and artificially reduced volatile matter contents of the bituminous coals investigated, an approximate linear relationship exists between the smoke index and the volatile matter content. The slope of the straight line for natural coals differs radically, however, from that of coal processed by the method herein described, as shown by figure 16 which is a composite of figure 15 and figures 5 and 6 (Part I of report).

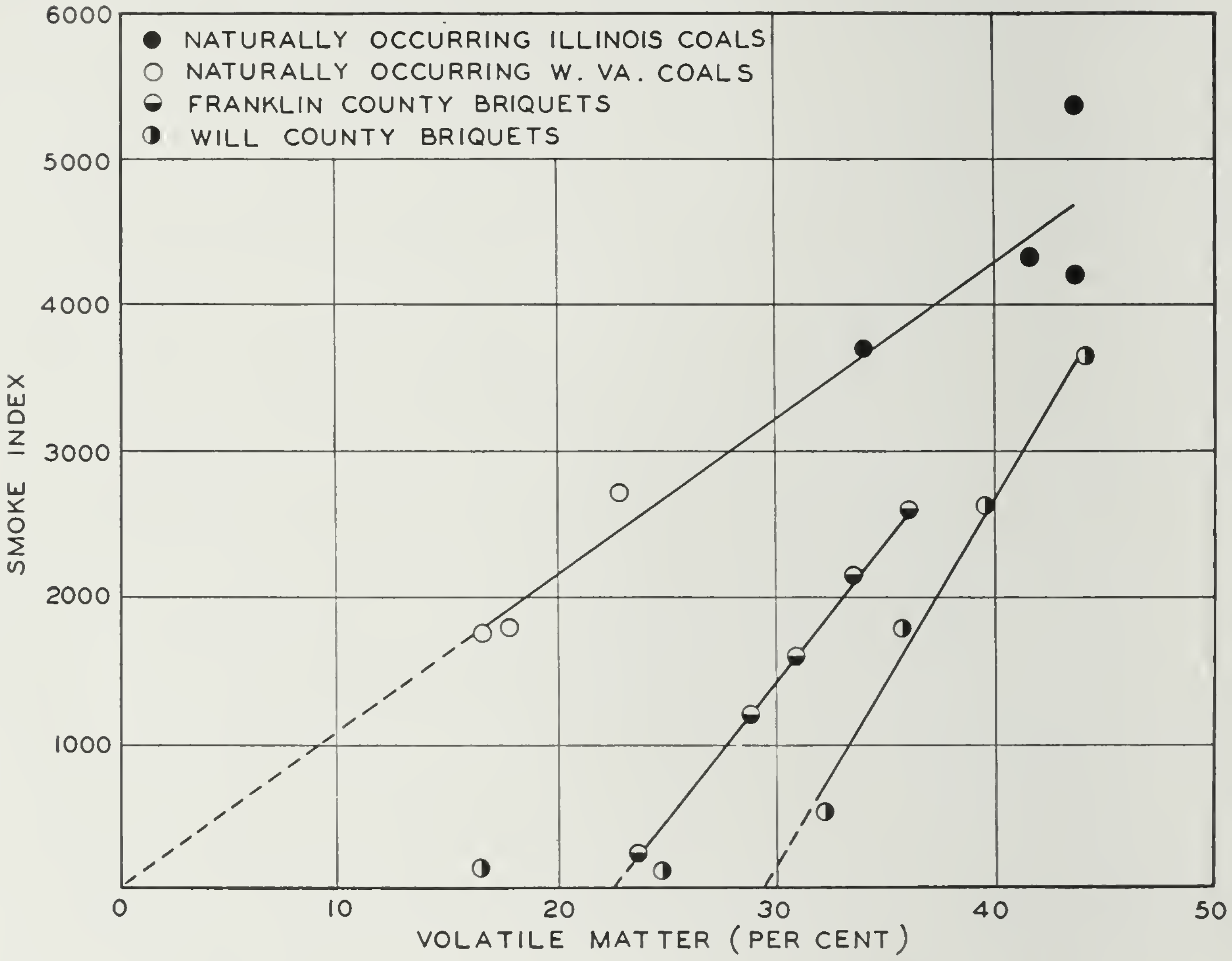

Fig. 16.—Effect of Amounts of Volatile Matter on the Smoke Index of Illinois and West Virginia Coals and Briquets Made From Franklin and Will County Coals. (Fig. 15, p. 90, and Figs. 5 and 6, Pt. I, pp. 27, 28.)

RELATIONSHIP BETWEEN SMOKE INDEX AND VOLATILE MATTER CONTENT OF NATURAL BITUMINOUS COALS

Referring again to figure 15, which shows a straight-line relationship between smoke index and volatile matter content for the natural coals investigated, it may be noted that the dotted extrapolation line intersects the axes at their zero value. In other words, there is an approximate direct proportionality between smoke content and volatile matter content for these coals. This seems to indicate that (with respect to its smoke content) the type of volatile matter present in these various coals is practically identical, the amount of the smoke per gram of the volatile matter being practically the same for the bituminous coals investigated.

However, it is well known that some coals possess a widely different smoke content from that of other coals containing the same percentage of volatile matter. It remains for future investigation to show whether or not a family of smoke index curves characterize coals having different botanical constitution.

SMOKE INDICES OF BRIQUETS MADE BY IMPACT FROM PROCESSED ILLINOIS COALS COMPARED WITH THOSE MADE DIRECTLY FROM NATURAL COALS

An examination of figure 16 shows a contrast in the rate of decrease of smoke index with volatile matter content for processed and natural coals. For example, in the instance of processed Will County coal (Fig. 5, Part I of report), the briquetted sample with a volatile matter content of 31.9 per cent (reduced from a natural volatile matter content of 43.9 per cent) has a smoke index of 250. Thus, processed coals from Will and Franklin counties can be made which possess less than one-third and one-seventh, respectively, of the smoke index of that of a natural West Virginia coal, even though the latter has a lower percentage of volatile matter.

IMPORTANCE OF ELIMINATING THE HIGH-SMOKE-INDEX FRACTION OF THE VOLATILE MATTER

Referring again to figures 5 and 6 (Part I of report), which show a straight-line relationship between smoke index and volatile matter content for briquets of partially volatilized coals from Will and Franklin counties, it may be noted that the dotted extrapolated lines intersect the volatile matter axis at 29 per cent and 23 per cent, respectively. Thus the smoke index decreases far more rapidly than the volatile matter content. This seems to indicate that in the process herein described there is a fractionation of the volatile matter whereby the high-smoke-index fraction is liberated, whereas the low-smoke-index fraction is retained in the processed coal.

Therefore for the purpose of obtaining a smokeless fuel for compaction into briquets from Illinois coals, it is essential only to apply heat sufficient to remove volatile matter which is driven off at comparatively low temperature.

RELATIONSHIP BETWEEN TEMPERATURE AND TIME IN EFFECTING DIFFERENT AMOUNTS OF VOLATILIZATION

This study consisted of: (a) the determination of the effect of volatilization temperature on the amount of volatile matter removed during a 10-minute volatilization period; and (b) the determination of time-temperature curve for 15 per cent volatile matter loss.

Effect of volatilization temperature on amount of volatile matter removed.—The effect of the temperature of volatilization on the amount of volatile matter reduction was determined for both Will and Franklin County coals using a volatilization period of 10 minutes.

Will County coal.—The effect of the temperature of volatilization, with a range from 350° to 530°C. (coal temperature), on the percentage of volatile matter in Will County coal, volatilized for a 10-minute period, is shown in figure 17 (Table 38). It may be noted from the figure that the volatile reduction starts at 420°C., the amount of reduction increasing with temperature.

TABLE 38.—VOLATILE MATTER CONTENT OF WILL COUNTY COAL AS AFFECTED BY VARIOUS VOLATILIZATION TEMPERATURES MAINTAINED FOR 10 MINUTE PERIODS (DATA FOR FIG. 17)

Volatilization coal temperature (°C.)	Oven temperature (°C.)	Weight loss (per cent)	Volatile matter (*a*) (per cent)
350	400	0.0	43.9
373	425	0.5	43.7
395	450	1.2	43.2
426	480	1.9	42.8
430	475	2.8	42.3
448	490	5.8	40.5
460	500	6.9	39.8
466	510	8.8	38.5
475	520	11.8	36.4
475	525	11.3	36.8
485	530	12.7	35.7
494	540	16.2	33.0
505	550	17.6	31.9
530	575	(*b*)	(*b*)

(*a*) Percentage volatile matter calculated from experimental weight loss.
(*b*) Weight loss could not be determined because no briquet was formed.

Franklin County coal.—Similar results for briquets made from Franklin County coal, volatilized for a 10-minute period at a coal temperature ranging from 250° to 482°C. are shown in figure 18 (Table 39). By extrapolation the initial temperature of volatile matter reduction appears to be about 410°C.

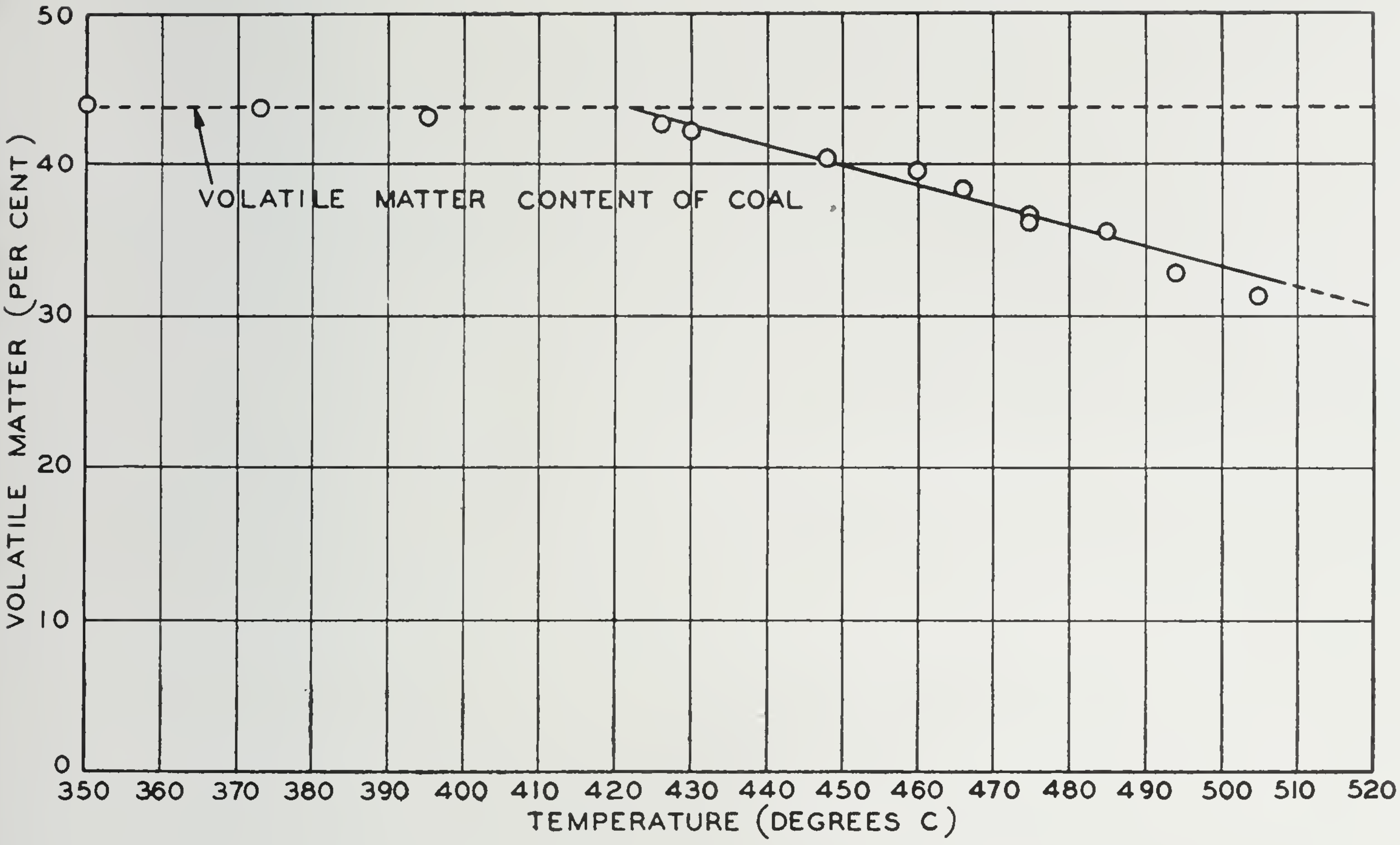

Fig. 17.—Volatile Matter Content of Will County Coal as Affected by Various Volatilization Temperatures Maintained For 10-Minute Periods.

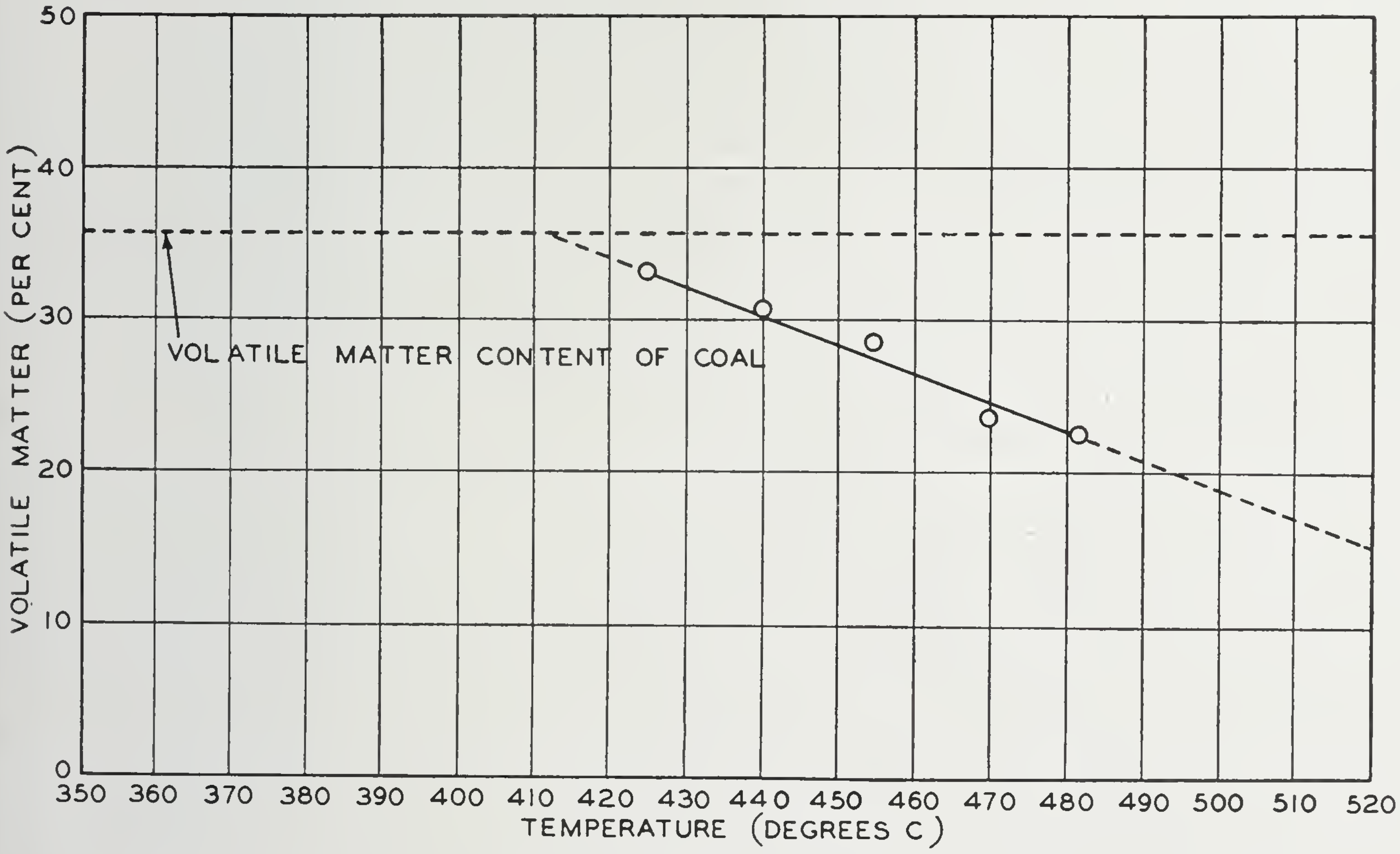

Fig. 18.—Volatile Matter Content of Franklin County Coal as Affected by Various Volatilization Temperatures Maintained For 10-Minute Periods.

TABLE 39.—VOLATILE MATTER CONTENT OF FRANKLIN COUNTY COAL AS AFFECTED BY VARIOUS VOLATILIZATION TEMPERATURES MAINTAINED FOR 10 MINUTE PERIODS (DATA FOR FIG. 18)

Volatilization coal temperature (°C.)	Oven temperature (°C.)	Weight loss (per cent)	Volatile matter (*a*) (per cent)
250	275	0.0	35.9
425	460	4.3	33.0
440	480	7.3	30.9
455	500	10.3	28.6
470	520	16.1	23.6
482	540	17.2	22.6

(*a*) Percentage volatile matter calculated from experimental weight loss.

TIME-TEMPERATURE CURVE FOR 15 PER CENT VOLATILE MATTER LOSS

Table 38 shows the volatile matter content of Will County coal volatilized at various temperatures for various periods of time. As shown previously (p. 28), on "as received" basis, a 15 per cent reduction in volatile matter results in a smokeless coal, with a smoke index less than one-third that of a West Virginia coal. For a coal containing about 10 per cent moisture, 15 per cent reduction on "as received" basis is equivalent to between 16 and 17 per cent reduction on a dry basis. Thus an optimum volatile matter loss of 16 per cent, dry basis, reduces this Will County coal from 43.9 to about 34 per cent volatile matter, which was selected as the optimum volatile matter content for smokeless briquets from this coal. Figure 4 (Part I of report) is a graph of the time-temperature curve for such an optimum volatile matter loss. As expected, the period necessary for the desired degree of volatilization decreases rapidly with increasing temperature.

DISCUSSION

For Will County coal, prevolatilized for a 10-minute period, volatilization starts at about 420°C., and the percentages of remaining volatile matter decrease linearly with temperature. For Franklin County Coal, volatilization starts at about 410°C., or 10° less than that for Will County coal. The percentages of remaining volatile matter, likewise, decrease linearly with temperature for the same period, the rate of decrease being apparently the same as that for Will County coal.

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18. Shaw, J. F., and Hurley, T. F., Methods and standards of smoke measurement: Fuel Econ. Rev. *9*, 97, 99-105 (1930).

    States determination of smoke in terms of suspended matter per unit weight of chimney gas is too complicated for plant use. Discusses Ringelmann and similar methods for determining smoke densities.

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20. Matson, P. D., and Kibler, A. S., The relation between obscuring power and particle number and size of screening smoke: J. Phys. Chem. *35*, 1074-90 (1931).

    Tests are made to check as to whether obscuring power of smoke (chemical) was related to its particle number and size.

21. Wordley, W. A., Some experiments on the measurement of smoke under industrial conditions: Fuel Econ. Rev. *10*, 89-92, 94-6 (1931).

    Instrument consists of a source of light passing through a tube across the smoke stack, a selenium cell at the other end of the tube, relay and signal bell.

22. Bailey, Compensated smoke recorder: Power Plant Eng. *38*, 388 (Aug. 1934).

    Describes photo-electric smoke recorder which uses two cells in parallel, one for detection, the other for compensation. Differential voltage is recorded, accurately representing the smoke density regardless of fluctuation in the system.

23. Electrical eye detects smoke: Power Plant Eng. *34*, 447 (Apr. 1930).

Describes unit developed by Zworykin at Westinghouse for measuring smoke density in stack. Lamp and cell are both mounted in tubes outside stack. Continuous recorder used.

24. Hannigan-McPherson smoke indicator: Power Plant Eng. *35*, 869 (Aug. 1931).

Describes apparatus in which smoke is passed through a glass chamber with a light behind it. Visual observations are made.

25. Indicator for determining smoke density: Mech. Handling *19*, 21 (Jan. 1932).

Describes "Smoke meter" in which light is sent across the path of the smoke and the absorption measured visually by comparison with Ringelmann scale.

26. Instrument for indicating and recording the density of smoke, liquids or dust: Power *69*, 679-80 (1929).

Describes photo-electric unit consisting of voltage regulator, lamp, photo-cell, amplifier, recording milliammeter, chart recorder. The detector is a length of pipe which admits a definite fraction of the total smoke.

27. Leads and Northrup smoke recorder: Power Plant Eng. *35*, 868 (Aug. 1931).

Describes use of a lamp and thermopile as a means of measuring the density of the smoke in a stack.

28. Photo-electric smoke recorder. Engineering *134*, 165-6 (1932).

Describes recorder made by Cambridge Instrument Company in which no light falls upon photo-cell unless smoke particles enter and act as secondary sources by diffraction.

29. Smoke detection. Engineer *155*, 606-7 (1933).

Describes photo-electric unit manufactured by Automatic Light Control, Ltd., for stack regulation. Uses selenium cell, washed windows in stack walls constant film of water. Uses temperature and voltage regulators. Unit makes a chart, sounds warning signals and lights lamp.

30. Encyclopedia Britannica. 14 Ed., Vol. 20, p. 839. Discussion of smoke.

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REPORT OF INVESTIGATIONS—NO. 42

SOME GEOLOGICAL RELATIONS BETWEEN THE CONSTITUTION OF SOIL MATERIALS AND HIGHWAY CONSTRUCTION

BY

GEORGE E. EKBLAW AND RALPH E. GRIM

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SOME GEOLOGICAL RELATIONS BETWEEN THE CONSTITUTION OF SOIL MATERIALS AND HIGHWAY CONSTRUCTION[1]

GEORGE E. EKBLAW[2] AND RALPH E. GRIM[3]

GEOLOGY AND ENGINEERING

GEOLOGY is an important factor in practically every engineering project that deals with earth materials. In some fields of engineering the geological factor is so evident that it is universally recognized; in others its relations to the engineering problems may be so obscure that it is overlooked or ignored. However, the part that geology plays in all fields of engineering is becoming ever better appreciated, as is demonstrated by the increasing attention and care that is being paid to adequate exploration and testing of geological materials and structures with reference to proposed dams and reservoirs, canals and locks, sewer trenches, tunnels, foundations for buildings and bridges, underpasses, excavations and fills, etc.

Although there has been highway engineering almost ever since man found it desirable to travel from place to place, the modern profession had its inception hardly more than a quarter of a century past. In that brief span of time it has achieved distinction favorably comparable to that attained by other older fields of engineering. When paved highways were first constructed, they were designed by engineers who were experienced in constructing paved city streets, gravel or stone pikes, railways, and similar developments. Since then the technique of highway construction in all its phases has progressed to a high degree, and searching investigations into many of its problems have been undertaken and aggressively pursued.

In the demand for paved highways that increased when the benefits of the first ones laid down were appreciated, one fundamental factor in their construction—the geological situation—was almost universally ignored as unimportant, generally from lack of knowledge of its possible consequences. However, these consequences have eventually made themselves evident, and as a result a policy of intelligent caution and investigation concerning geological matters is being rapidly adopted. The highway engineers in almost every state, as well as in the Federal bureau and in many county and similar organizations, are devoting more and more attention to the geology of the materials underlying and bounding the highway and of those of which the highway itself is built.

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[1] Presented at the Twenty-eighth Annual Meeting of the Mississippi Valley Conference of State Highway Departments, Stevens Hotel, Chicago, Illinois, February 7, 1936, and at the Twenty-third Annual Conference on Highway Engineering at the University of Illinois, Urbana, February 28, 1936.

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ENGINEERING GEOLOGY IN ILLINOIS

Not many years after the program of improved highway construction in Illinois was begun, there appeared certain difficulties which the engineers of the State Division of Highways recognized as probably due to geologic conditions. These problems were referred to the State Geological Survey for counsel and to them Dr. M. M. Leighton, Chief, gave his personal attention for several years. Through these services, as well as similar services provided for problems concerning dams and reservoirs and other engineering projects presented to the Survey, the field of engineering geology in the State was established. It grew rapidly so that in 1927 the Division of Engineering Geology of the State Geological Survey was organized, with Dr. Ekblaw in charge.

At first, the problems presented by the highway engineers concerned only landslides and mudflows, with consequent dislocation of alignment and fractured or wavy pavements, and estimates of earth and rock to be excavated in highway construction, but in the nearly nine years that Dr. Ekblaw has continued the cooperation with them, the highway engineers have presented scores of situations, no two of which have ever been identical although they can be grouped into a relatively few classes of problems. Moreover, as an undoubted result of the engineers' better acquaintance with geology and consequent better appreciation of its application in highway construction, the field included by the problems they have presented has steadily broadened. Landslides of all types and sizes, seepage and drainage, peat bogs, location of fills, materials for fills, character of aggregate materials, selection of proposed highway routes, heaving and cracking of pavements, bridge foundations, and grade separations—either underpass or overhead—include most of the specific problems. Also, in 1929 and 1930, at the request of the State Division of Highways, the State Geological Survey carried on over most of the State a detailed reconnaissance of limestone and sand and gravel deposits suitable for local sources of materials for secondary roads. Within the last two years the highway engineers have asked for particular information as to deposits of plastic clay suitable for use in stabilized gravel roads.

PRESENT TRENDS

An account of the geology concerned with some of these problems, its significance, and the measures consequently adopted would be interesting but would probably only duplicate experiences of every highway engineer. Therefore, the present discussion is restricted to some considerations concerning soil materials that have probably never occurred to engineers as having any special bearing on highway construction but which we hope to show are actually of fundamental importance, especially in view of the present emphasis on better subgrades, better subgrade drainage, and stabilized gravel roads. The same considerations also more or less directly play a part in many of the other geological highway construction problems.

The two most recent problems on which the Illinois State highway engineers have sought our geologic advice have emphasized these very considerations. The problems have concerned failure of pavements at localities and in situations where it would hardly be expected. One case occurred in Lake County, where in situations that appear to have at least reasonably good drainage it is found that at times of heavy rain, water collects between the pavement and the subgrade, softens the surface of the subgrade, and thereby destroys its supporting power; the pavement vibrates under impact of traffic and pumps muddy water out through joints, cracks, and along the sides of the slab; and eventually so much of the subgrade is thus removed along transverse joints that the pavement settles, cracks, and is ruined. The other case occurred in Greene County, where in similar situations of apparently reasonably good drainage a "black-top" pavement has repeatedly failed. Again examinations revealed that during rainy periods water accumulates between the bearing course and subgrade, the pavement vibrates under traffic and pumps out muddy water through cracks, thus removing the supporting base, and eventually the pavement fails. An added factor in this case is the fact that because the pavement is not rigid, traffic traveling in relatively narrow lanes tends to press the pavement in these lanes down into the subgrade when it is softened by the water, and thus creates ruts in the subgrade in which more water accumulates, aggravates the situation, and hastens the disruption of the surface. It is obvious that these undesirable conditions result solely because the soil material on the subgrade and in the shoulders is relatively so impervious that the water cannot escape either downward or laterally but accumulates between the pavement and the subgrade; it is also obvious that the remedy consists of altering or amending the construction design to provide means either of preventing excess water, especially that drained off the pavement surfaces themselves, from getting under the slab or of removing it as rapidly as it accumulates. However, these conclusions do not answer the question raised by the engineers as to why such conditions occur at some places and not universally in the State. The studies of clay minerals as carried on by Dr. Grim during the past four years and as applied to soil materials provide some interesting data pertinent to the question.

SURFICIAL MATERIAL

In Illinois, as in the other states of the Mississippi Valley, most of the subgrade on which highways are constructed is unconsolidated material, and in the states in the upper Mississippi Valley a part of the unconsolidated material is glacial drift, that is, material that was picked up by the continental glaciers which spread from Canada over northern United States, was carried by them to localities far from their source, and was dropped when the glaciers melted away (Fig. 1). Much of the surficial material is loess, a deposit of silt derived from various sources and carried and laid down by the wind, and the rest is alluvium deposited either by glacial or present streams.

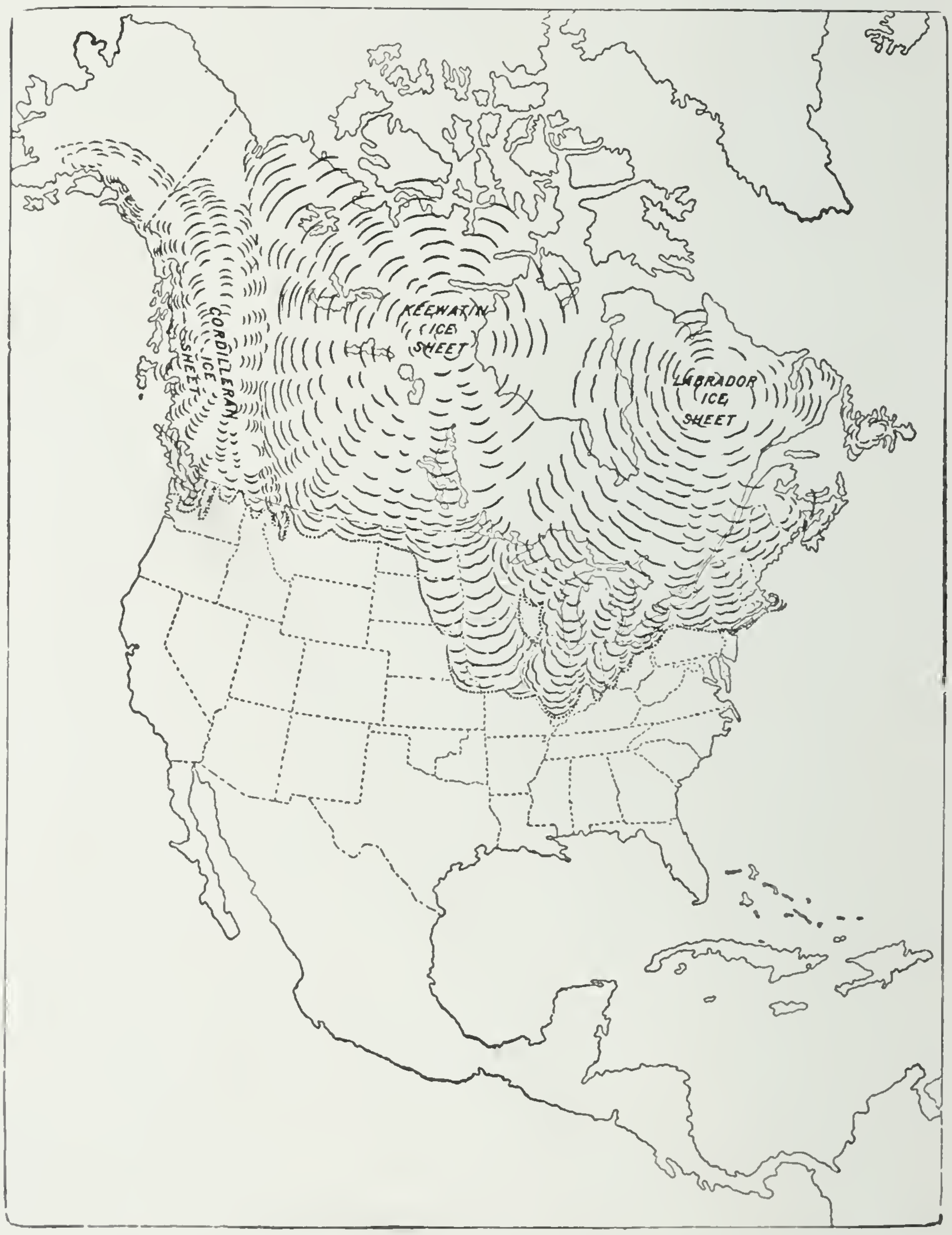

Fig. 1.—Map of North America Showing the Centers of Ice Accumulation and the Area of Glaciation

Four distinct glaciers successively invaded northern United States and are named, in order of age, Nebraskan, Kansan, Illinoian, and Wisconsin (Table 1). Between each two glacial stages there was an interval of time during which the climate was much the same as at present, so that on the preceding glacial drifts operated the same processes that are now operating, and one of these is the formation of soils. Consequently at some places we

TABLE 1.—THE GLACIAL STAGES OF NORTH AMERICA

Glacial invasions	Interglacial epochs
Wisconsin (fourth)	
	Sangamon (third)
Illinoian (third)	
	Yarmouth (second)
Kansan (second)	
	Aftonian (first)
Nebraskan (first)	

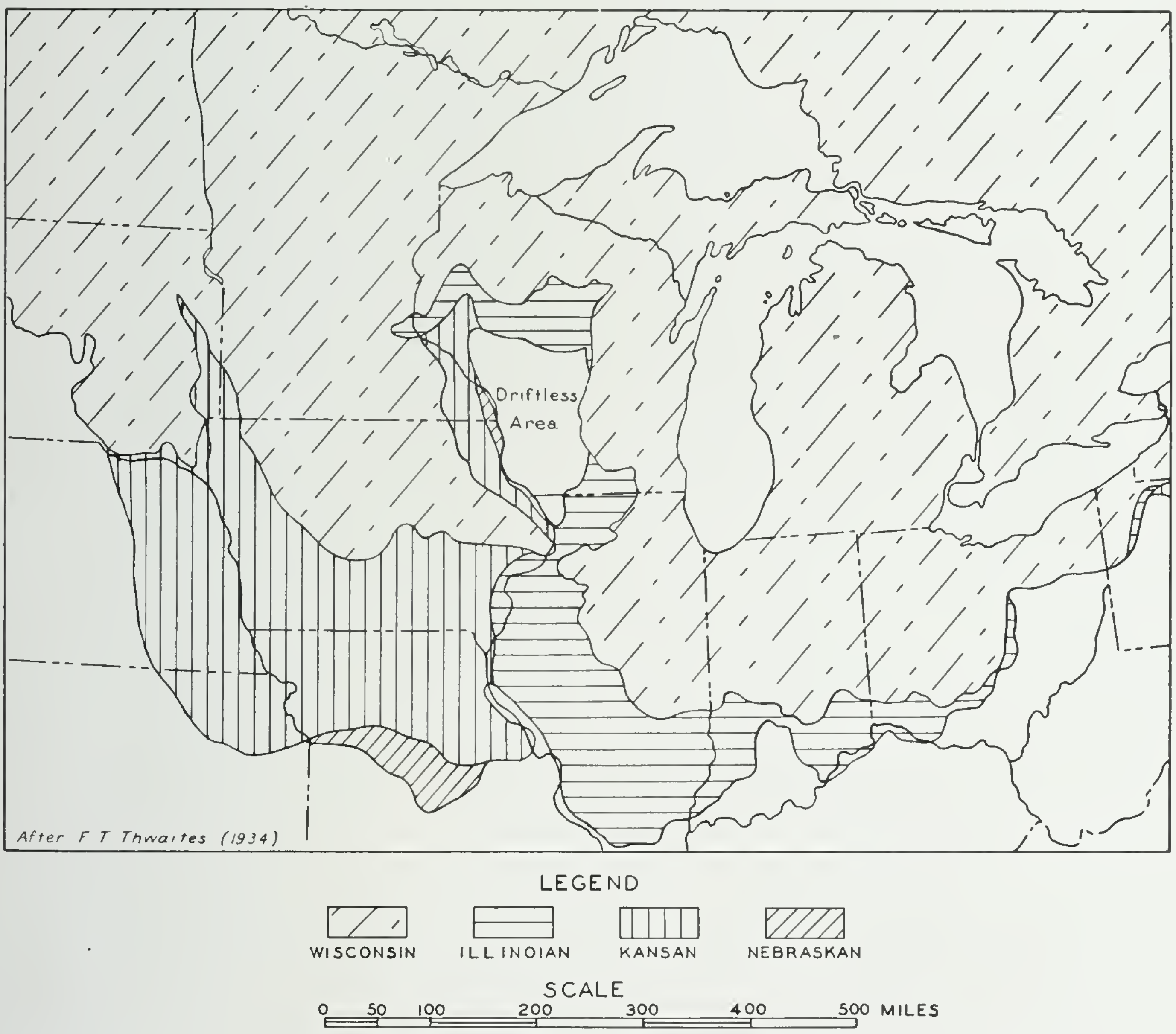

Fig. 2.—SURFICIAL DISTRIBUTION OF GLACIAL DRIFT-SHEETS IN THE UPPER MISSISSIPPI VALLEY

find two or more deposits of glacial drift, each separated by a soil horizon. The Nebraskan and Kansan drifts are found in Nebraska, Kansas, southern Iowa, and Missouri as far south as Missouri River; the Illinoian drift occurs in southern and western Illinois, southeastern Iowa, southern Indiana, and southern Ohio; the Wisconsin drift covers northern Ohio, northern Indiana, northeastern Illinois, northern Iowa, and the other northern states (Fig. 2).

SOIL PROFILES

Geologists recognize that in the formations of soils there are four major chemical reactions which, in the order of their relative rate of progress, are respectively (1) formation of humus organic material, (2) oxidation, (3) leaching or solution of lime and magnesium carbonates, etc., and (4) decomposition of silicate minerals with consequent concentration of colloidal material.

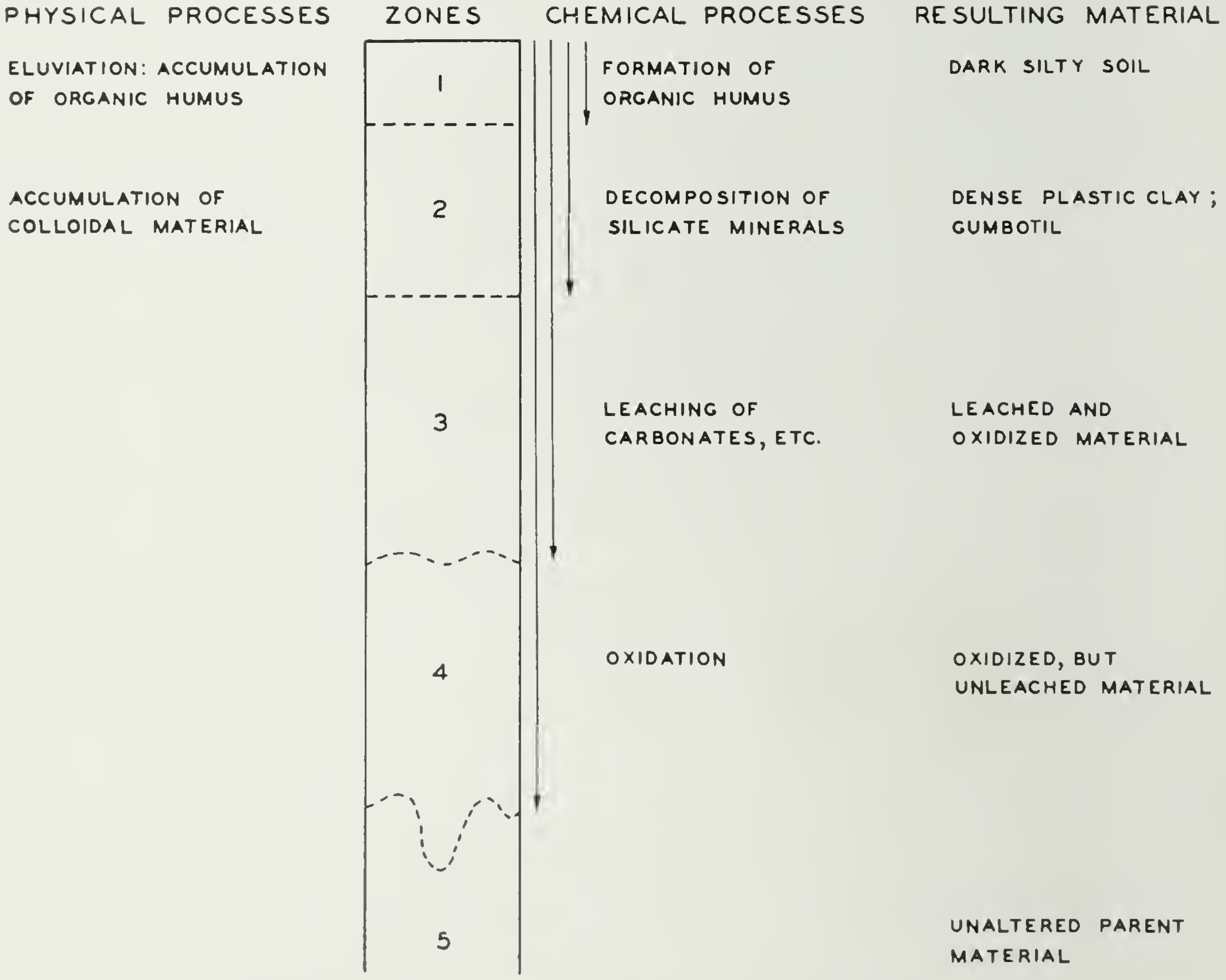
PHYSICAL PROCESSES
ZONES
CHEMICAL PROCESSES
RESULTING MATERIAL
ELUVIATION: ACCUMULATION OF ORGANIC HUMUS
1
FORMATION OF ORGANIC HUMUS
DARK SILTY SOIL
ACCUMULATION OF COLLOIDAL MATERIAL
2
DECOMPOSITION OF SILICATE MINERALS
DENSE PLASTIC CLAY; GUMBOTIL
3
LEACHING OF CARBONATES, ETC.
LEACHED AND OXIDIZED MATERIAL
4
OXIDATION
OXIDIZED, BUT UNLEACHED MATERIAL
5
UNALTERED PARENT MATERIAL

Fig. 3.—Generalized Diagram of a Maturely Developed Soil Profile and the Processes Involved in its Development (After Leighton and MacClintock

A typical well-developed soil profile on glacial material consists of four major horizons (Fig. 3) which, from top to bottom, are (1) the humus horizon, a black or gray silty zone generally not more than several inches thick, (2) a zone of dense oxidized leached clay, typically gray but locally reddish, hard when dry and generally plastic when wet, and practically impervious to all drainage, (3) an oxidized, leached zone, and (4) an oxidized but calcareous zone, beneath which occurs the unaltered parent material (5). The thickness of these zones depends on the length of time the soil-forming processes have operated. All of them are well developed in the soil profiles formed on all the glacial drifts except the last one (Wisconsin). Because zone 2, when typically developed from glacial till over broad flat areas, is extremely plastic and gumbo-like, it has been termed gumbotil. It is a reliable source of plastic clay in almost all of the territory covered by the three older glacial drifts. Zone 2, as developed on deposits of fine loess, is also a possible source of plastic clay but is not so satisfactory as the gumbotil. The density and general imperviousness of this zone are the factors that contribute so greatly to the problem of satisfactorily draining subgrades in so many places in the Mississippi Valley.

With these general relationships of glacial drifts and soil-profile zones in mind, we shall proceed to a consideration of the constitution of clays and soils.

RELATIONS BETWEEN CONSTITUTIONS AND PROPERTIES OF CLAYS AND SOILS

It is obvious that the character and properties of the materials on which the highways are directly laid will exert a tremendous influence on their durability and permanence. Every engineer knows that not all soils possess the same properties and that different soils yield different results when highways are built over them or when they are used in fills. Further, it is obvious that the most satisfactory material for fills cannot be selected from that available in a given area and the most satisfactory subgrade drainage cannot be designed until it is known why different soils possess different physical properties. This knowledge is necessary before an examination and consequent determination that certain specific materials will have certain properties and other material will have other specific properties can be intelligently made.

Soils, clays, tills, loess, and shale are all argillaceous materials—that is, they contain clayey material and possess properties, such as plasticity when wet, which are associated with the term clay. The physical properties of argillaceous materials are dependent upon their constitution. The important factors of constitution influencing physical properties are texture, chemical composition, mineral composition, and base-exchange characteristics. The literature contains the results of much research on the influence of the first two factors. It is known, for example, that in general the finer the grain size of such material, the greater the plasticity, water adsorptive ability, shrinkage, etc., and that electrolytes exert a great influence on the degree to which clays can be placed in suspension in water. More recent research has emphasized the importance of the mineral composition and base-exchange characteristics as factors determining the properties of argillaceous materials.

It has shown that two clays may have the same grade size distribution and yet possess different physical properties if their mineral compositions are different. Likewise, two clays may yield the same ultimate chemical composition but possess different physical properties if their mineral compositions and base-exchange characteristics are different. Research into the mineral composition and base-exchange properties of argillaceous materials and the influence of these factors of constitution on physical properties has been Dr. Grim's major interest in recent years.

DETERMINATION OF CONSTITUTION OF CLAYS AND SOILS

Complete research into the mineral composition of these materials is of relatively recent date for the reason that satisfactory research tools and methods for studying the finest constituents have been only recently developed. It is comparatively easy to identify the mineral constituents in the coarser grade sizes, but special technique is necessary to identify those in the finest grade sizes, particularly those of colloidal size, that is, those which have to be measured in fractions of a micron. In the laboratory of the Illinois State Geological Survey a research procedure has been devised whereby complete thoroughgoing data on the mineralogy of clays can be obtained by special microscopic technique using magnifications up to 1500 diameters, by improved X-ray technique, and by chemical analysis following separation of the material into mineral concentrates by means of a supercentrifuge. The clays are literally taken apart into their component mineral constituents. It is these constituents in the finest fractions which are most important in influencing physical properties.

This work has shown (1) that the concept that all clays contain a mysterious universal clay substance, sometimes called clayite, to which they owe their properties, is fallacious; (2) that the concept that all clay materials are composed essentially of the mineral kaolinite is erroneous; (3) that an alternative concept that these materials are simply heterogeneous assemblages of almost any species of minerals existing in very small particles and that therefore their properties are entirely dependent upon the size-grade distribution of the component particles is also erroneous; and (4) that they contain little or no amorphous material.

On the contrary, this work has shown that clays actually are composed of crystalline constituents throughout—even the colloidal fraction is composed of crystalline particles, the colloidal properties depending on smallness of particle size and also on the shape of the individual particles. It has also substantiated the concept, which has become increasingly prevalent in recent years, that argillaceous materials are composed essentially of one or more of a comparatively small group of minerals known as the clay minerals (Table 2).

TABLE 2.—CLAY MINERALS

Name	Chemical composition	Remarks
Kaolinite	$Al_2O_3.2SiO_2.2H_2O$	Anauxite and kaolinite form an isomorphous series
Anauxite	$Al_2O_3.3SiO_2.2H_2O$	
Halloysite	$Al_2O_3.2SiO_2.xH_2O$	
Beidellite	$Al_2O_3.3SiO_2.xH_2O$	Beidellite and nontronite form an isomorphous series
Nontronite	$Fe_2O_3.3SiO_2.xH_2O$	
Montmorillonite	$Al_2O_3.4SiO_2.H_2O$	Montmorillonite, beidellite, and nontronite probably contain essential alkalies or alkaline earths
Sericite-like mineral	$2K_2O.3MO.8R_2O_3.24SiO_2.12H_2O$	

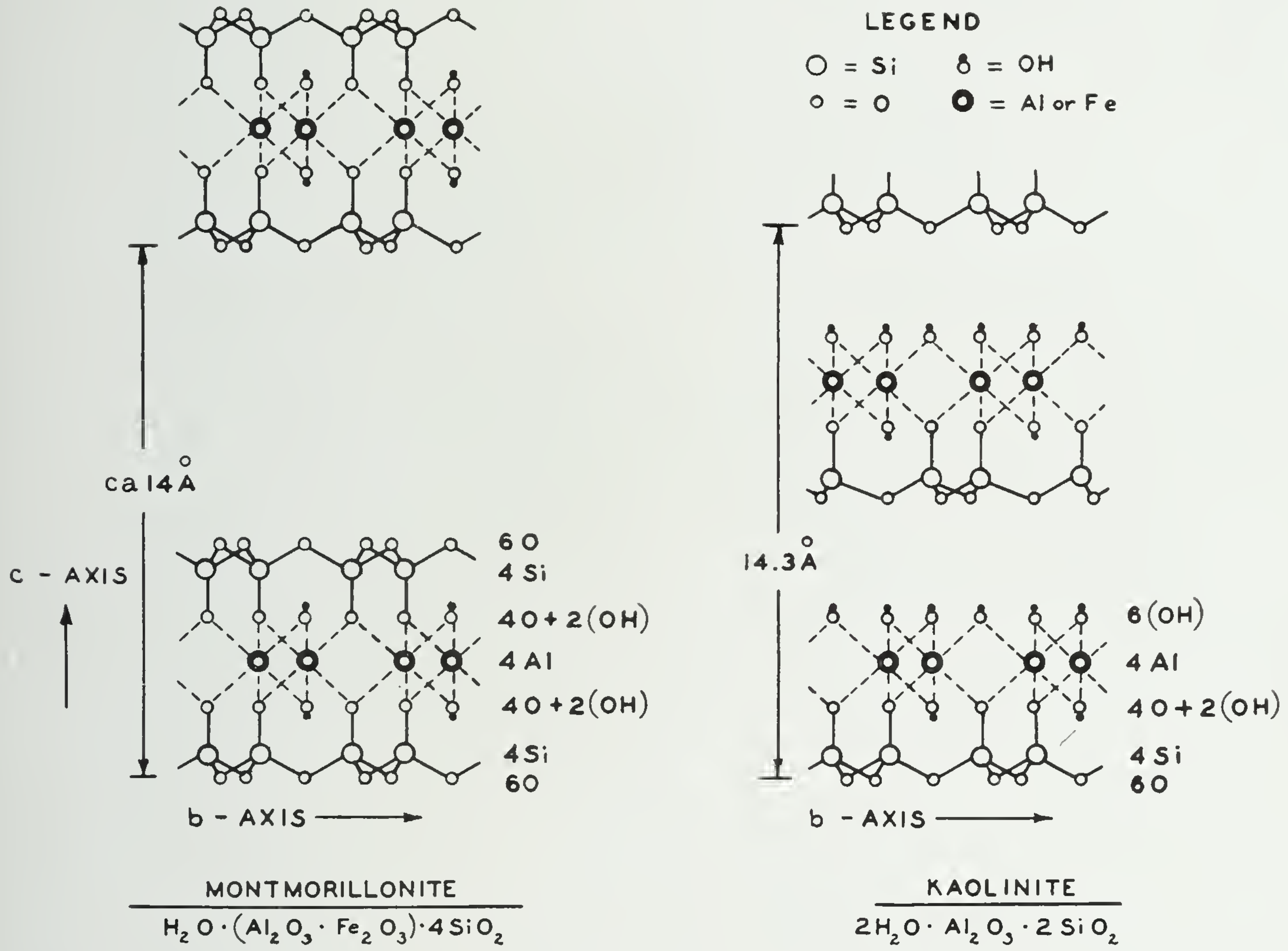

Fig. 4.—SCHEMATIC REPRESENTATION OF LATTICE STRUCTURE OF THE CLAY MINERALS MONTMORILLONITE AND KAOLINITE (after Endell, Hofmann, and Wilm) showing the layered arrangement that accounts for their flake-like crystals. Note the great and variable interval between the successive layers in montmorillonite, as compared with the limited interval in kaolinite, which accounts for its greater adsorptive ability and other properties.

They are hydrous aluminum silicates and some of them also contain alkalies or alkaline earths. In most of them the aluminum may be isomorphously replaced by ferric iron. At the present stage of the researches, it is not possible to write exact formulae for all of them; the formulae of beidellite, nontronite, and the unnamed sericite-like mineral particularly are to be regarded as tentative. The sericite-like mineral is so named because it resembles the sericite form of white mica. It is possible that future research will show that there are a few other clay minerals. All the clay minerals have a general micaceous crystalline habit, as a consequence of which their individual particles are flat and flake-shaped (Fig. 4). It is important to note that the flake-shaped characteristic is not developed to the same degree in all clay minerals.

COMPOSITION OF SOME COMMON "SOIL MATERIALS"

The essential features of the mineral composition of the several argillaceous materials commonly encountered in highway construction are as follows:

Gumbotil is composed essentially of beidellite in particles .00006 mm. in diameter or in slightly larger particles, .001-.0001 mm. in diameter, which are easily reduced by slight working of the material to the finer grade size. In addition to beidellite, silty gumbotil contains the sericite-like mineral and also quartz varying in amounts according to the degree of siltiness. Coarser grains of quartz and possibly large grains of other minerals are present if the gumbotil is sandy.

The finest grade sizes, that is clay-size grades, of *till* are composed of a mixture of beidellite and the sericite-like mineral. If the till is calcareous, calcite is present in particles which may attain a minimum size of .0001 mm. The coarser fractions of till are mixtures of quartz and fragments of a variety of different minerals and rocks. Different tills vary from each other in the relative abundance of these constitutions, but the relative abundance of beidellite and the sericite-like mineral are of prime importance in influencing physical properties.

Loess is composed primarily of quartz and mica with a smaller quantity of a variety of other minerals, such as feldspar, pyroxene, and amphibole, all existing in particles ranging in size from about .06 to .001 mm. A small amount of finer material, which is a mixture of beidellite and the sericite-like mineral, is present. Calcite is present if the material is calcareous.

The finest grade sizes of *soil developed on loess* in Illinois are a mixture of beidellite, the sericite-like mineral, organic material, limonite (hydrated ferric oxide), and quartz. The coarser fractions have compositions similar to those of the coarser fraction of the loess from which the soil was derived. These constituents are not present in uniform amounts in all soils nor are they uniformly distributed vertically from the top of the soil downward, but are to a large degree dependent on the maturity of the soil and the drainage conditions under which it has developed. Thus, organic material tends to occur mainly in the surface horizon (Fig. 3, zone 1). Beidellite is a secondary product derived from the alteration of many of the primary constituents. It forms primarily in the upper horizon and as the soil profile develops it is carried downward and redeposited a short distance beneath the surface. As a result, zone 2 of the soil profile is formed as an impervious horizon, whose thickness and depth vary with the age of the soil, and at the same time the top horizon consequently becomes increasingly silty. When the soil profile has reached a fairly advanced stage of weathering, the beidellite is decomposed into its constituent oxides and rounded limonitic aluminous pellets tend to develop at or near the base of zone 2. The process of leaching, by which downward seeping groundwater removes from the upper horizon not only the calcite but also any alkalies that may be present, causes the upper horizons of the soil profile to become acid.

RELATION BETWEEN MINERAL CONSTITUENTS AND PROPERTIES OF SOILS

The next step of our research has been to determine the influence that specific mineral constituents exert on the physical properties of the materials containing them. It has been found, for example, that beidellite and montmorillonite differ from kaolinite and the sericite-like mineral in possessing far higher adsorptive ability for water; in the ability to break down easily to extremely small particles, e. g., beidellite commonly occurs in particles less than .00006 mm. or can easily be reduced to this size whereas the sericite-like mineral and kaolinite rarely are in particles smaller than .0001 mm.; and in their ability to possess exchangeable bases. It follows from these and other considerations that increasing amounts of beidellite in a soil will increase its plasticity, its stickiness, its impervious character, and the swelling and shrinkage on the addition or removal of moisture. Stated another way, two soils, one of which is largely composed of beidellite and the other of the sericite-like mineral, may have about the same size grade distribution in the natural state and about the same ultimate chemical analysis, but when these soils are utilized, the one containing the most beidellite will tend to be most impervious, stickiest, most plastic, and most subject to volume variation.

The addition of electrolytes has been known for some time to cause changes in the physical properties of clays. In the last few years the relation of this phenomenon to base-exchange has been recognized and its importance has been realized. Clays possess the ability to carry bases which, under certain conditions, can be exchanged for other bases. Thus, if a clay containing exchangeable calcium is treated with a strong solution of a sodium salt, the sodium will go into the clay replacing the calcium which will come out in the solution. Opinions differ as to whether the exchangeable bases are held on the surface of the colloidal particles or within their lattice structure. Likewise, opinions differ as to whether it is a stoichiometrical chemical reaction or simply adsorption.

The seat of the exchange capacity is in the clay mineral content, and different clay minerals possess different exchange capacities. Thus, the exchange capacity for montmorillonite is very high, for beidellite it is moderately high, and for kaolinite and the sericite-like mineral it is low. Obviously soils composed of beidellite will have higher exchange capacity than those composed of the sericite-like mineral. Therefore, whatever influence base-exchange phenomena exert on physical properties will be reflected to a higher degree by those composed of beidellite than those composed of the sericite-like mineral.

Certain properties of soils vary with the identity of the exchangeable base they contain. For example, the plasticity of a given clay or soil differs according to whether sodium or calcium is the exchangeable base. The shrinkage can be changed by substituting calcium for sodium. A soil saturated with sodium is far more impervious to water than an acid soil or one in which calcium is the exchangeable base.

The reason for this influence may be conceived in part by considering the flake-shaped clay mineral particles to be encased in a hull of basic ions which in turn is enclosed by a hydration sphere. Probably because different ions have different dissociation abilities, the hydration sphere varies with the identity of the exchangeable base and the physical properties show a correlative variation.

In the present state of information it is impossible to give much specific data and many detailed conclusions on this subject. The Illinois State Geological Survey has under way extensive researches to determine the constitution, particularly the mineral constitution, and base-exchange characteristics of the argillaceous materials occurring within the State. Our object is further to determine exactly how these factors influence the properties of the material as a whole, which, in turn, determine its utilization, and thereby to extend and to improve their utilization in the field of ceramics and in other fields in which such materials are used. Our researches have progressed so far that a comparatively rapid petrographic microscopic analysis of the mineral composition of these materials commonly enables a prediction of their physical properties. However, this procedure is not intended as a substitute for actual testing, but its value lies primarily (1) in selecting from material available that which is most satisfactory for a given purpose, and (2) in the search for the seat of trouble in material which has already been used.

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M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 43

ILLINOIS MINERAL INDUSTRY IN 1935

A Preliminary Statistical Summary and Economic Review

BY

WALTER H. VOSKUIL, ALMA R. SWEENY AND W. A. NEWTON

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ILLINOIS MINERAL INDUSTRY IN 1935

A PRELIMINARY STATISTICAL SUMMARY AND ECONOMIC REVIEW

Walter H. Voskuil, Alma R. Sweeny and W. A. Newton

INTRODUCTION

THIS REPORT, which presents the fundamental statistics in the distribution and consumption of the major mineral products of the State, is made possible through the cooperation of the United States Bureau of Mines and the Bureau of the Census of the United States Department of Commerce, through the active collection and publication of coal statistics by the Illinois State Department of Mines and Minerals, and through the generous cooperation of the mineral producers of the State in responding to requests for information.

The quantity and value of mineral output in Illinois in 1934 and 1935 is shown in Table 1.

There was increased activity in all branches of the mineral industry during the year 1935. Severe winter weather not only increased coal shipments but resulted in an early depletion of coal stocks in the Upper Lake docks with a consequent increased demand upon Illinois and Indiana fields.

Revival of the steel industry increased operations in the fluorspar district of the State. Stocks on hand were substantially reduced and the statistical position of the industry is considerably improved.

The clay products industry is gradually bringing about a reduction of excessive stocks and with increasing building activity, production schedules can soon be increased.

Increased construction activity also improved the demand for sand, gravel, limestone, and cement.

Table 1.—Preliminary Summary of Production and Value of Illinois Minerals, 1934–1935

Product	1934		1935	
	Tons	Value	Tons	Value
Coal	41,272,384	$64,238,000	43,845,000	$70,152,000
Pig Iron	1,430,841	25,357,717	2,224,132	39,092,488
Clay products	...	5,945,199	...	6,820,145
Coke	1,649,907	9,071,800	1,668,523	9,628,162
Cement, Portland (barrels)	3,908,107	5,498,568	3,276,970	4,500,897
Sand and gravel (total)	6,174,202	3,373,690	8,354,473	4,276,342
Structural sand	606,354	302,558	1,158,015	454,427
Paving and roadmaking sand	1,014,805	419,832	901,428	387,925
Glass sand	448,804	449,832	470,546	554,322
Moulding sand	347,078	320,242	465,871	439,194
Railroad ballast sand	161,348	65,774	411,333	118,811
Grinding, polishing and blast sand	107,366	334,953	115,293	367,302
Engine sand	39,000	21,546	45,809	25,820
Fire or furnace sand	(a)	(a)	(a)	(a)
Other sands	123,129	125,675	144,585	108,851
Structural gravel	602,212	315,864	1,376,076	613,573
Paving and roadmaking gravel	2,265,690	872,444	2,312,064	908,718
Railroad ballast gravel	291,166	62,193	822,589	250,416
Other gravel	167,250	82,777	130,864	46,983
Petroleum (barrels)	4,479,000	...	4,305,000	4,864,465
Limestone (total)	3,901,560	2,881,651	4,027,838	2,927,381
Road metal and concrete	2,667,242	1,963,405	2,516,494	1,742,168
Flux	257,650	149,225	337,618	177,131
Railroad ballast	228,517	150,263	389,646	257,572
Rip-rap	192,360	207,751	213,498	213,882
Rubble	68,450	47,690	39,935	45,990
Agriculture	448,810	291,761	320,080	221,704
Other uses	38,531	71,556	210,567	268,934
Mineral paints, zinc and lead pigments	...	...	...	...
Natural gasoline (gallons)	3,733,307	182,771	...	...
Natural gas (M. cu. ft.)	...	...	...	...
Lime (total)	86,679	655,359	117,602	878,746
Building	14,113	120,079	17,078	146,201
Tanneries	(a)	(a)	(a)	(a)
Metallurgy	(a)	(a)	35,219	234,075
Paper mills	3,121	20,427	8,230	46,201
Other uses	69,445	514,853	57,077	452,069
Fluorspar	33,234	567,396	44,120	685,794
Quartz (silica)	50,748	285,849	66,492	370,488
Clay (raw)	69,921	160,537	98,743	278,658
Tripoli	7,417	119,418	10,001	113,484
Lead and silver	...	3,160	...	...
Sandstone	3,900	5,761	18,400	12,869
Zinc	...	...	...	...
Pyrites	...	...	1,114	...
Total	...	$97,479,159	...	$105,509,437

[a] Included in other uses.

COAL

Review of production.—Coal production rose from 11.5 per cent of the national total in 1934 to 11.9 per cent of the national total in 1935 (Table 2). The high point of Illinois percentage of the total was 16.7 per cent in 1921, while the low point occurred in 1927 when it was 9.0 per cent. This, however, was an abnormal year due to suspension of mining operations during part of the year. During the period 1919 to 1935 the average share by Illinois of the total coal demand was 12.7 per cent.

Table 2—Summary of Coal Production, 1933–1935
(In thousands of net tons)

Year	United States	Illinois	Illinois per cent of total
1933	333,631	37,413	11.2
1934	359,368	41,272	11.5
1935([a])	369,324	43,845	11.9

[a] Preliminary figures.

The production of shipping mines in Illinois, by months, as shown by the Illinois Department of Mines and Minerals, is given in Table 3.

Distribution of coal in the Illinois coal market area.—Table 4 gives a summary of all-rail revenue coal (exclusive of railway fuel) shipped into the Illinois coal market area by market districts in 1934 and 1935.

Shipments of coal from central and southern Illinois to Chicago increased substantially over 1934 and show a continuous increase since 1932, while shipments from western Kentucky and Indiana have remained practically constant. Shipments from western Kentucky to Illinois outside of Chicago dropped off substantially although coal consumption increased. Most of the increase was supplied by Illinois mines.

The principal eastern competitors of Illinois coal in the Chicago market, the New River-Winding Gulf and the Pocahontas-Tug River fields in West Virginia, still show increased shipments each year. Harlan and Hazard fields in eastern Kentucky, while not as large shippers of coal as the West Virginia fields, have doubled their shipments to Chicago since 1932. Kanawha (West Virginia), Logan, and Kenova-Thacker fields show a small decline in 1935 shipments as compared to 1934.

Shipments of Illinois coal to Milwaukee, although small, trebled from 1934 to 1935, and increased substantially in other Wisconsin territory.

Table 3.—Bituminous Coal Production by Shipping Mines in

County	January	February	March	April	May
Christian	405,147	386,249	420,207	261,399	296,322
Clinton	42,795	28,319	28,584	4,572	5,124
Franklin	985,397	772,733	958,253	270,532	434,454
Fulton	207,230	186,248	203,354	90,748	114,744
Henry	45,289	42,339	50,113	39,775	33,841
Jackson	132,300	132,342	113,592	76,792	63,428
LaSalle	26,026	20,234	23,216	15,190	13,804
Macoupin	370,476	367,625	418,177	169,257	289,659
Madison	218,505	187,860	164,948	87,218	29,548
Marion	39,844	33,575	45,588	([b])	([b])
Montgomery	63,379	55,952	69,082	([b])	34,351
Peoria	144,012	128,977	133,372	67,780	96,770
Perry	349,906	365,625	403,757	183,157	203,161
Randolph	47,624	44,933	81,198	12,354	40,690
Saline	401,751	373,173	350,309	100,308	134,201
Sangamon	293,218	286,577	321,029	67,865	128,448
St. Clair	274,422	226,826	221,436	72,560	75,439
Tazewell	25,353	20,179	18,163	11,199	([b])
Vermilion	201,628	197,140	222,042	113,457	135,506
Washington	46,029	42,330	45,225	15,008	20,131
Williamson	276,190	251,601	333,519	114,596	154,599
Woodford	15,562	13,632	12,189	([b])	([b])
Other Counties	190,737	177,714	181,754	133,775	112,044
Total	4,802,820	4,342,183	4,819,107	1,908,115	2,416,264
Strip Mines	673,614	671,973	721,717	426,912	447,765
Shaft Mines	4,129,206	3,670,210	4,097,390	1,481,203	1,968,499

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[a] Compiled from Coal Report for 1935, Illinois State Department of Mines and Minerals.

[b] Tonnage included in other counties.

llinois, by Counties and Months, for 1935 [a] (In net tons)

June	July	August	September	October	November	December	1935 Total
345,349	268,054	296,129	213,400	355,120	278,060	384,924	3,910,360
(b)	(b)	11,840	19,324	32,751	19,226	40,831	233,366
614,510	260,216	433,406	494,763	1,001,107	820,938	942,672	7,988,981
104,310	133,955	118,223	109,918	217,148	194,423	215,185	1,895,486
45,256	38,116	46,720	39,889	58,597	51,739	55,609	547,283
71,566	70,158	105,204	89,621	171,579	99,399	145,771	1,271,752
8,077	4,886	14,724	21,837	32,896	29,244	33,145	243,279
304,818	212,882	223,998	279,922	296,972	337,718	401,135	3,672,639
64,998	41,586	56,274	105,901	170,211	137,551	180,567	1,445,167
(b)	(b)	16,197	20,919	39,538	40,414	43,839	279,914
35,816	27,977	33,857	43,361	45,599	53,384	63,148	526,206
(b)	(b)	37,020	71,326	129,694	108,164	141,034	1,058,149
245,858	163,998	179,549	159,433	371,547	287,096	348,225	3,261,312
47,305	16,729	17,793	48,886	40,220	61,858	63,158	522,748
160,885	124,767	180,224	280,849	350,420	290,237	400,201	3,147,325
117,973	64,306	81,559	169,933	235,491	276,180	291,673	2,334,252
101,849	69,760	95,881	154,306	236,986	189,103	254,887	1,973,455
(b)	(b)	2,816	14,297	13,699	15,114	19,997	140,817
136,613	82,035	63,581	89,867	136,437	120,868	175,753	1,674,927
29,004	15,731	15,264	15,632	49,247	39,482	41,323	374,406
220,229	145,573	172,524	164,895	365,612	298,764	273,545	2,771,647
(b)	(b)	(b)	8,908	13,227	9,729	13,042	86,289
233,547	140,801	84,765	126,066	169,917	183,587	234,231	1,968,388
2,887,963	1,881,530	2,287,548	2,743,253	4,534,015	3,942,278	4,763,895	41,328,971
505,368	414,361	454,974	425,513	796,033	712,170	803,640	7,054,040
2,382,595	1,467,169	1,832,574	2,317,740	3,737,982	3,230,108	3,960,255	34,274,931

Table 4.—Origin and Destination of Revenue Railroad Shipments From (Exclusive of Non-Revenue

From	Chicago, Illinois	Illinois, other	Milwaukee, Wis.	Wisconsin, other	Council Bluffs, Iowa
1934					
Western Pennsylvania	19,858	1,530	340	496	....
Altoona, Somerset-Meyersdale and Cumberland-Piedmont	31,455	4,674	413	2,586	772
Fairmont (W. Va.)	10,864	7,555	92	1,323	....
Northern and Eastern Ohio	2,120	....	....	944	....
Southern Ohio	3,201	280	....	493	....
Kanawha, (W. Va.) Logan, and Kenova-Thacker (W. Va.-E. Ky.)	865,362	105,197	1,421	42,798	1,274
New River–Winding Gulf and Pocahontas-Tug River	5,987,987	417,313	122,516	534,235	77
Northeast Kentucky and McRoberts	812,537	236,818	601	43,192	....
Virginia	86,865	14,051	....	25,941	....
Harlan and Hazard (E. Ky.)	1,136,387	279,383	1,513	46,481	618
Ex-River Coal	....	248	....	....	....
Northern Illinois	660,261	1,720,818	162	53,130	44
Central and Southern Illinois	5,013,206	5,697,164	16,293	665,931	42,455
Indiana	2,778,257	1,005,808	46,403	471,015	1,466
Western Kentucky	560,775	334,767	1,442	301,323	7,707
Total	17,969,135	9,825,606	191,196	2,189,888	54,413
1935					
Western Pennsylvania	51,515	45	....	647	....
Altoona, Somerset-Meyersdale and Cumberland-Piedmont	45,379	5,471	372	5,403	733
Fairmont (W. Va.)	11,825	4,159	....	940	....
Northern and Eastern Ohio	929	....	....	1,098	....
Southern Ohio	1,762	87	....	228	....
Kanawha (W. Va.), Logan and Kenova-Thacker (W. Va.-E. Ky.)	718,957	104,602	1,879	42,616	1,230
New River–Winding Gulf and Pocahontas-Tug River	6,379,274	378,286	122,155	534,217	98
Northeast Kentucky and McRoberts	793,829	122,093	1,180	35,982	....
Virginia	116,018	15,855	43	34,288	....
Hazard, Harlan, and Southern Appalachians	1,950,545	342,080	2,130	46,306	834
Ex-River Coal	470	....	....	....	....
Northern Illinois	461,974	1,877,469	1,132	83,978	....
Central and Southern Illinois	5,659,803	6,440,315	47,765	1,043,677	46,533
Indiana	2,859,975	1,032,359	72,820	418,830	153
Western Kentucky	603,154	357,087	1,720	285,069	6,180
Total	19,655,409	10,679,908	251,196	2,533,279	55,761

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[a] Data from U. S. Bureau of Mines, Monthly Coal Distribution Reports.

llinois, Indiana, and Western Kentucky and From the Appalachians
Railroad Fuel)[a]

Iowa, other	St. Louis, Missouri	Kansas City	St. Joseph	Missouri, other	Kansas, other	Nebraska, other	Minnesota	South Dakota	North Dakota
				1934					
521	....	17	....	....	....	....	172	38	......
3,011	3,331	859	417	2,008	1,261	1,508	4,509	1,454	......
2,313	....	....	....	....	....	....	475	167	......
4,453	....	....	....	....	....	....	239	73	......
487	....	....	....	....	....	....	100	....	......
179,372	42,399	....	....	2,819	....	438	25,194	2,979	......
86,465	59,558	....	....	681	218	393	139,063	17,995	......
158,901	177,011	50	....	1,737	....	716	28,162	4,379	......
4,142	183	....	....	....	....	....	8,630	363	......
375,048	6,258	....	....	1,820	....	1,302	38,661	8,890	......
....	....	....	....	....	....	....	....	....	......
311,550	96	....	....	....	....	....	50,118	1,827	......
,350,047	2,939,703	3,813	21,193	790,262	13,833	114,712	374,372	100,772	1,234
361,770	44,528	97	....	1,310	....	4,906	149,836	24,064	491
268,983	96,051	189	....	113,548	....	15,138	72,039	26,947	3,524
,107,063	3,369,118	5,025	21,610	914,185	15,312	139,113	891,570	189,948	5,249
				1935					
271	....	....	....	....	....	....	296	....	......
5,261	3,412	1,050	339	2,362	1,662	1,393	4,750	1,313	......
2,073	....	....	....	....	....	....	843	201	......
5,907	....	....	....	....	....	....	75	40	......
3,800	....	....	....	....	....	....	447	....	......
195,376	64,248	....	....	2,493	....	442	20,919	2,089	......
86,619	75,307	....	....	1,078	83	115	141,361	15,671	......
172,292	138,189	....	....	1,130	....	729	27,991	3,174	......
4,340	....	....	....	....	....	....	8,786	952	......
474,453	7,606	....	....	2,089	....	1,695	47,237	7,531	......
....	....	....	....	....	....	....	....	....	......
376,410	479	....	....	240	....	235	64,658	625	......
,503,507	3,067,025	4,606	33,267	892,121	19,387	130,938	435,626	121,804	1,796
401,107	47,996	152	....	2,804	....	3,494	134,936	10,413	181
299,576	86,135	50	....	66,584	....	14,322	58,114	26,957	4,531
,530,992	3,490,397	5,858	33,606	970,901	21,132	153,363	946,039	190,770	6,508

Table 5 shows the origin and destination of coal into the Illinois coal market area, by percentages of total shipments received, for the past six years. Only fields shipping more than one per cent of the total all-rail shipments are included. The table of shipments to Chicago, for example, shows a slow decline after 1932, the year of prolonged suspension of mining in Illinois, for all important fields except two. These two fields are Harlan and Hazard, and Northeast Kentucky and McRoberts. The Illinois fields have regained a portion of the Chicago market since the low period of 1932 but Indiana and Kentucky, the two competitors in the Eastern Interior field, have not. However, there was a substantial increase in shipments from these two fields between 1930 and 1932 and much of this gain is still being held.

A further study of these tables shows that the principal competition of the eastern coal fields is localized mainly in the Chicago market area, in Wisconsin, and in Minnesota. A considerable portion of this probably represents coal used for domestic heating. The consumption of fuels for domestic heating in this area, including fuel oil and natural gas, is approximately equivalent to 14 or 15 million tons of coal. Only a small part of this is shared by Illinois fields.

Illinois coal shipments to Wisconsin.—An interesting feature of coal distribution since 1930 is the increasing shipments of coal from Illinois to Wisconsin. The heaviest coal consumption in Wisconsin is in the lake shore counties and secondly, in the southern part of the state. The lake shore market has long been dominated by shipments from eastern fields over the lakes. Nevertheless, coal from southern Illinois is being marketed in small but increasing quantities in the Milwaukee market and has made substantial gains in other Wisconsin markets. The record of revenue rail shipments from Illinois into this territory is shown in Table 6.

Table 5.—Origin and Destination of Coal into the Illinois Coal Market Area, by Percentages of Total Shipments, 1930–1935

(Shipments less than 1 per cent not included)

From	1930	1931	1932	1933	1934	1935
Shipments to Chicago						
Kanawha, Logan, and Kenova-Thacker	5.51	5.06	4.99	4.85	4.81	3.66
New River-Winding Gulf and Pocahontas-Tug River	32.05	33.9	35.90	33.50	33.30	32.42
Northeast Kentucky and McRoberts	5.85	4.17	2.97	3.94	4.52	4.04
Hazard, Harlan, and Southern Appalachians	11.20	9.45	6.30	7.32	6.32	9.96
Northern Illinois	2.30	2.87	3.64	3.52	3.68	2.59
Central and Southern Illinois	29.80	30.2	23.3	27.80	27.90	28.82
Indiana	5.81	10.1	16.41	15.30	15.46	14.51
Western Kentucky	2.64	2.98	6.05	3.15	3.12	3.06
Other Fields	4.84	1.27	.44	.62	.89	.94
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Other Illinois Points						
Kanawha, Logan, and Kenova-Thacker	1.47	2.72	1.76	1.42	1.07	.98
New River-Winding Gulf and Pocahontas-Tug River	....	3.95	3.69	4.35	4.25	3.54
Northeast Kentucky and McRoberts	....	1.12	2.16	2.50	2.40	1.14
Hazard, Harlan, and Southern Appalachians	4.08	5.51	5.06	4.27	2.84	3.20
Northern Illinois	11.48	10.52	12.26	13.49	17.50	17.60
Central and Southern Illinois	65.5	61.4	53.70	57.90	57.90	60.40
Indiana	9.36	9.8	11.28	11.09	10.20	9.70
Western Kentucky	6.36	4.8	9.89	4.77	3.40	3.35
Other Fields	1.75	.18	.20	.21	.44	.09
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Milwaukee						
Kanawha, Logan, and Kenova-Thacker	4.21	2.86	1.98	....	....	....
New River-Winding Gulf and Pocahontas-Tug River	71.0	74.3	76.5	77.7	64.10	48.60
Northeast Kentucky and McRoberts	2.65	1.51	....	....	....	....
Virginia	1.02	....	1.17	....	....	....
Hazard, Harlan, and Southern Appalachians	1.57	2.0	2.16	1.32	....	....
Central and Southern Illinois	10.35	9.58	5.44	4.35	8.52	19.50
Indiana	7.12	7.12	9.00	11.50	24.30	29.00
Western Kentucky	1.07	1.58	2.30	3.14	....	....
Other Fields	1.01	1.05	1.45	1.99	3.08	2.90
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 5.—Origin and Destination of Coal (*Continued*)

From	1930	1931	1932	1933	1934	1935
Shipments to Other Wisconsin Points						
Kanawha, Logan, and Kenova-Thacker	10.50	4.48	4.26	3.32	1.95	1.68
New River-Winding Gulf and Pocahontas—Tug River	32.10	29.3	32.39	30.80	24.4	21.20
Northeast Kentucky and McRoberts	8.6	5.5	4.24	3.62	1.97	1.42
Virginia	....	1.21	1.75	1.37	1.18	1.35
Hazard, Harlan and Southern Appalachians	9.47	3.24	3.64	3.70	2.12	1.83
Northern Illinois	....	....	....	....	2.42	3.31
Central and Southern Illinois	19.6	24.8	19.4	23.61	30.40	41.10
Indiana	7.46	14.06	17.38	19.41	21.52	16.51
Western Kentucky	10.1	16.41	15.71	13.40	13.71	11.30
Other Fields	2.17	.10	1.23	.77	.33	.33
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Council Bluffs, Iowa						
Kanawha, Logan,and Kenova-Thacker	1.58	2.92	2.96	3.28	2.34	2.20
Hazard, Harlan, and Southern Appalachians	....	1.34	1.50	2.1	1.13	1.50
Central and Southern Illinois	65.9	70.5	77.0	75.20	78.00	83.40
Indiana	2.17	3.99	1.91	1.11	2.70	....
Western Kentucky	28.8	20.2	15.4	16.10	14.15	11.1
Other Fields	1.55	1.05	1.23	2.56	1.68	1.80
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Other Iowa Points						
Southern Ohio	....	....	....	....	....	1.00
Kanawha, Logan, and Kenova-Thacker	7.75	6.78	7.37	6.62	5.77	5.40
New River–Winding Gulf and Pocahontas–Tug River	2.60	2.54	2.54	2.76	2.78	2.46
Northeast Kentucky and McRoberts	6.11	6.3	6.00	5.41	5.10	4.88
Hazard, Harlan, and Southern Appalachians	13.0	12.51	13.8	13.50	12.09	13.40
Northern Illinois	3.76	5.48	5.2	8.50	10.01	10.68
Central and Southern Illinois	45.95	45.1	37.8	40.90	43.49	42.50
Indiana	8.2	9.45	8.86	9.00	11.62	11.30
Western Kentucky	11.98	11.2	18.11	12.70	8.65	8.30
Other Fields	.65	.64	.32	.61	.49	.08
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 5.—Origin and Destination of Coal (*Continued*)

From	1930	1931	1932	1933	1934	1935
Shipments to St. Louis, Missouri						
Kanawha, Logan, and Kenova-Thacker	1.34	....	1.11	1.37	1.26	1.84
New River–Winding Gulf and Pocahontas–Tug River	2.39	2.6	1.98	2.10	1.77	2.16
Northeast Kentucky and McRoberts	4.45	5.7	5.58	5.76	5.25	3.96
Central and Southern Illinois	87.3	86.75	77.8	84.50	87.20	87.90
Indiana	....	....	1.90	1.94	1.32	1.37
Western Kentucky	3.5	2.92	11.50	3.97	2.85	2.46
Other Fields	1.02	2.03	.13	.36	.35	.31
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Kansas City, Missouri						
Central Pennsylvania, Somerset-Meyersdale and Cumberland-Piedmont	1.36	2.05	9.24	12.45	17.10	17.91
Central and Southern Illinois	98.	97.5	89.4	84.65	76.00	78.50
Indiana	....	....	....	2.05	1.93	2.6
Western Kentucky	....	....	....	....	3.76	.99
Other Fields	.64	.45	1.36	.85	1.30	....
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to St. Joseph, Missouri						
Central Pennsylvania, Somerset-Meyersdale and Cumberland-Piedmont	1.18	1.84	1.85	1.65	1.00	1.00
Kanawha, Logan, and Kenova-Thacker	1.94	....	....	....	....	....
Central and Southern Illinois	96.2	95.2	98.00	97.90	99.00	99.00
Other Fields	.68	2.96	.15	.45	....	....
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Other Missouri Points						
Central and Southern Illinois	82.8	84.5	75.0	83.20	86.50	91.90
Indiana	1.12	....	....	....	....	....
Western Kentucky	14.55	13.5	23.2	15.33	12.52	6.85
Other Fields	1.53	2.0	1.8	1.47	.98	1.25
Total	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 5.—ORIGIN AND DESTINATION OF COAL (*Continued*)

From	1930	1931	1932	1933	1934	1935
Shipments to Other Kansas Points						
Central Pennsylvania, Somerset-Meyersdale and Cumberland-Piedmont	2.86	3.29	7.34	7.25	8.25	7.87
New River-Winding Gulf and Pocahontas-Tug River	......	......	......	......	1.25	......
Hazard, Harlan, and Southern Appalachians	5.21	......	......	......	......	......
Central and Southern Illinois	89.4	95.2	90.0	92.00	90.50	91.70
Indiana	1.73	......	......	......	......	......
Western Kentucky	......	......	1.00	......	......	......
Other Fields	.80	1.51	1.66	.75	......	.43
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Other Nebraska Points						
Central Pennsylvania, Somerset-Meyersdale and Cumberland-Piedmont	......	......	......	1.00	1.08	......
Kanawha, Logan,and Kenova-Thacker	2.0	1.31	......	......	......	......
Hazard, Harlan, and Southern Appalachians	2.52	2.41	1.53	......	......	1.12
Central and Southern Illinois	82.4	82.5	80.9	81.30	82.50	85.30
Indiana	4.16	3.91	4.21	3.94	3.52	2.27
Western Kentucky	7.64	8.11	11.61	12.19	10.89	9.34
Other Fields	1.28	1.76	1.75	1.57	2.01	1.97
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to Minnesota						
Kanawha, Logan, and Kenova-Thacker	3.04	2.34	2.58	3.42	2.82	2.21
New River-Winding Gulf and Pocahontas-Tug River	14.1	16.45	20.59	21.61	15.60	14.95
Northeast Kentucky and McRoberts	5.55	5.06	4.28	4.40	3.16	2.96
Hazard, Harlan, and Southern Appalachians	5.10	4.65	5.14	4.95	4.34	5.00
Northern Illinois	13.31	15.28	11.00	6.78	5.61	6.82
Central and Southern Illinois	42.9	37.67	30.19	32.62	42.00	46.00
Indiana	4.93	8.80	11.49	15.12	16.80	14.20
Western Kentucky	9.35	8.65	13.50	9.49	8.08	6.14
Other Fields	1.72	1.10	1.23	1.61	1.59	1.72
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 5—Origin and Destination of Coal (*Concluded*)

From	1930	1931	1932	1933	1934	1935
Shipments to South Dakota						
Kanawha, Logan, and Kenova-Thacker	5.17	3.20	2.13	2.26	1.57	1.10
New River-Winding Gulf and Pocahontas-Tug River	12.10	10.51	14.5	14.64	9.47	8.20
Northeast Kentucky and McRoberts	5.19	6.93	2.7	4.10	2.31	1.66
Hazard, Harlan, and Southern Appalachians	8.86	7.4	5.74	6.54	4.69	3.95
Central and Southern Illinois	54.8	54.25	45.8	43.00	52.60	63.85
Indiana	....	....	1.22	9.84	12.68	5.46
Western Kentucky	12.0	16.11	25.91	17.75	14.20	14.11
Other Fields	1.88	1.60	2.00	1.87	2.48	1.67
Total	100.00	100.00	100.00	100.00	100.00	100.00
Shipments to North Dakota						
Northern Illinois	....	....	2.2	....	....	....
Central and Southern Illinois	28.09	40.5	11.50	16.73	24.07	27.60
Indiana	18.05	4.05	3.60	14.6	9.39	2.80
Western Kentucky	53.35	55.5	82.7	68.67	66.54	69.60
Other Fields	.51	.40	....	....	....	....
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 6.—Shipments of Coal from Central and Southern Illinois and from Northern Illinois to Wisconsin

	To Milwaukee (Tons)	To Other Wisconsin Points (Tons)
From Central and Southern Illinois		
1930	33,999	612,478
1931	23,875	443,930
1932	11,297	321,495
1933	10,872	409,127
1934	16,293	665,931
1935	47,765	1,043,677
From Northern Illinois		
1930	0	20,268
1931	0	9,759
1932	0	14,632
1933	154	16,812
1934	162	53,130
1935	1,132	83,978

The rapid gain in shipments from 1932, the low year, to 1935 cannot b accounted for solely by reviving industrial activity. Nor are the large shipment in 1935 explained by severe weather conditions since the cold winter weather o 1935-1936 had not yet affected coal shipments in December of 1935. A probabl explanation is the changing trend in consumer habits. It must be borne in mind that Wisconsin is located in a high-cost fuel area. For many years anthracit dominated the domestic fuel market until rising prices brought about the introduction of substitutes such as the smokeless coals of West Virginia, coke, briquet and fuel oil. Although these fuels are somewhat lower in price than anthracite, transportation and preparation costs tended to keep these fuels at a fairly high pric level. This is bringing about the introduction of stokers designed to burn lowe priced fuels, some of which are available from Illinois fields.

Wisconsin consumes annually an equivalent of about four or five million ton of coal for domestic and commercial heating. The competitive nature of the market is shown by the kinds of fuel used and the variety of sources from which it is obtained. The quantities of fuel used in the state can be partly estimated from isolated data available, as follows:

	Tons
Anthracite—1933	161,000
Briquets —1935	155,000
Coke —1929	408,000
Fuel oil—1934 (equivalent tons)	444,000
Bituminous coal—1934 (approximately)	3,000,000

Bituminous coal was obtained mainly from West Virginia, eastern Kentucky, Virginia, Illinois, Indiana, and western Kentucky fields. A consumption in excess o 1,000,000 tons of prepared fuels, approximately 25 per cent of the total required for heating purposes, and the importation over high freight rates of large quantitie of eastern coals indicates an opportunity for a capture of a larger portion of thi market by the lower priced Illinois coals if conditions of market demand are properly met. The introduction of stokers designed to handle Illinois coals appears t be one of the promising methods that can be employed in entering further into thi market.

Coal production in other states within the Illinois coal market area. n addition to shipments of coal from Appalachian, Indiana, and western Kenucky fields by all-rail and rail-lake hauls, the Illinois coal industry shares the narket with local production in states west of the Mississippi River. Production in hese states, 1930-1935, is as follows:

TABLE 7.—COAL PRODUCTION IN IOWA, KANSAS, MISSOURI, AND THE DAKOTAS
(In thousands of tons)

Producing State	1930	1931	1932	1933	1934	1935
owa	3,893	3,388	3,862	3,195	3,367	3,468
ansas	2,430	1,987	1,953	2,218	2,508	6,104
lissouri	3,853	3,621	4,070	3,432	3,352	
orth Dakota	1,700	1,519	1,740	1,782	1,754	1,872
outh Dakota	13	27	49	59	60	....
Total	11,889	10,532	11,674	10,686	10,975	11,444

Strip-mined coal in Illinois.—Coal mined by stripping methods showed substantial increase in 1935 over 1934. With the exception of 1932, when operations in shaft mines were suspended for several months, the percentage of total roduction reached the highest peak in 1935 (Table 8).

TABLE 8.—STRIP-MINED COAL IN ILLINOIS, 1929-1935

Year	Output, tons	Percent of total output
1929	5,374,813	8.8
1930	6,116,415	11.3
1931	6,262,501	14.6
1932	6,423,935	20.4
1933	5,423,796	15.4
1934	5,777,202	14.1
1935	7,054,040	16.1

Fuel briquets.—Distribution of fuel briquets in 1935 increased over the previous year in the Illinois coal market area. (Table 9). Particularly significant gains occurred in Wisconsin and Minnesota.

TABLE 9.—BRIQUETS CONSUMED FOR DOMESTIC FUEL IN THE ILLINOIS COAL MARKET AREA, 1931–1935[a]
(In net tons)

State	1931	1932	1933	1934	1935
Illinois	7,918	5,474	6,218	12,606	18,831
Wisconsin	77,907	65,872	89,131	104,885	154,857
Minnesota	200,583	137,292	133,102	168,067	195,384
Iowa	23,843	18,310	19,269	22,713	23,068
Missouri	4,271	3,005	4,360	5,904	7,564
North Dakota	52,288	43,915	46,746	50,525	60,419
South Dakota	39,490	29,999	28,704	34,401	43,596
Nebraska	16,975	8,245	8,992	16,171	15,214
Kansas	10,033	6,262	4,243	5,278	4,841
Total	433,308	318,374	340,765	420,550	523,774
Total for the United States	688,258	485,288	529,162	704,856	858,646

[a] U. S. Bureau of Mines, Weekly Coal Report 988—June 20, 1936.

Trend in natural gas consumption.—Importation of natural gas into the Illinois coal market area continued its upward trend in 1935 over previous years, although the rate of increase is declining. Detailed data of distribution are not yet available for 1935, but a total figure for the United States shows an increase of natural gas output.

Fuel oil.—Consumption of fuel oil and gas oil in the Illinois coal market area in 1935, the latest detailed data available, amounted to 38,024,000 barrels (Table 10). This is roughly equivalent to 9,500,000 tons of coal. In addition, 1,423,000 barrels of range oil, which is usually a partly refined kerosene, was used in cooking, space heating, and hot water heating. The largest single item of consumption is accounted for by domestic and commercial heating. A comparison with consumption of fuel oil in 1930 shows a decided increase in the use of oils for heating and a moderate increase in commercial and industrial uses. (Table 11).

A recent survey of fuel oil issued by the Oil Burner Institute shows that the wholesale fuel oil price per barrel of 42 gallons has been going up gradually during the past several years and that the 1935 price was on the same level as 1929. The wholesale price per barrel in both years was 89 cents. The price fell to 78 cents in 1930, 57 cents in 1931, 62 cents in 1933, and 83 cents in 1934. The prices are predicated on a weighted average of five refineries. The increasing use of diesel engine power is creating a demand which is competing with heating fuel oil and will tend to raise prices. The survey indicates that purchasers of fuel oil can anticipate a six to nine per cent increase in price yearly.

TABLE 10.—CONSUMPTION OF GAS OIL AND FUEL OIL IN THE ILLINOIS COAL MARKET AREA IN 1935
(Thousands of barrels of 42 gallons each)

	Commercial and Domestic heating	Industrial Uses	Total	Range Oil
Illinois	8,324	6,713	15,037	305
Wisconsin	2,227	765	2,992	153
Minnesota	2,497	489	2,986	209
Iowa	856	522	1,378	152
Missouri	3,509	3,074	6,583	232
North Dakota	227	42	269	44
South Dakota	283	191	474	61
Nebraska	789	526	1,315	81
Kansas	294	7,100	7,394	186
Total	19,006	19,422	38,428	1,423

TABLE 11.—CONSUMPTION OF GAS OIL AND FUEL OIL IN THE ILLINOIS COAL MARKET AREA 1930
(Thousands of barrels of 42 gallons each)

	Commercial and Domestic heating	Industrial Uses	Total
Illinois	3,101	9,526	12,627
Wisconsin	801	766	1,567
Minnesota	771	803	1,575
Iowa	321	785	1,106
Missouri	1,415	3,053	4,468
North Dakota	84	44	128
South Dakota	43	112	155
Nebraska	332	517	849
Kansas	110	4,551	4,661
Total	6,978	20,157	27,135

PETROLEUM

Production and price.—The production of petroleum in Illinois in 1934 and 1935 is given in Table 12.

TABLE 12.—PETROLEUM PRODUCED IN ILLINOIS IN 1934–1935
(In barrels of 42 gallons each)

Month	1934	1935	Month	1934	1935
January	393,000	332,000	July	394,000	377,000
February	337,000	295,000	August	402,000	379,000
March	394,000	370,000	September	378,000	370,000
April	373,000	338,000	October	352,000	391,000
May	411,000	382,000	November	305,000	369,000
June	392,000	358,000	December	321,000	344,000
First 6 months	2,300,000	2,075,000	Year	4,452,000	4,305,000

The average price for petroleum in 1935 was $1.23 compared with $1.13 in 1934 and $0.87 in 1933.

The consumption of major petroleum products.—The growing importance of petroleum products as a fuel for commercial and domestic heating is bringing to the foreground certain problems in the marketing of these products. Until recently, the principal cash crop of the petroleum industry was gasoline and lubricating oils, while fuel oil, the other principal commodity besides gasoline, was

TABLE 13.—CONSUMPTION OF MAJOR PETROLEUM PRODUCTS, 1926–1935
(In thousands of barrels of 42 gallons each)

Year	Gasoline[a]	Total Fuel Oil[b]	Oil Used for Heating[b]	Per cent Heating Oil of Total Fuel Oil
1926	195,322	334,030	22,780	6.8
1927	219,834	334,272	27,459	8.2
1928	255,705	353,232	30,699	8.7
1929	322,619	371,999	37,400	10.0
1930	375,287	267,361	43,279	11.8
1931	398,077	329,137	40,578	12.4
1932	368,938	301,570	44,264	14.7
1933	367,532	308,347	50,140	16.3
1934	395,123	330,321	60,822	18.4
1935	427,120	365,958	76,853	21.0

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[a] American Petroleum Institute.

[b] U. S. Bureau of Mines, National Survey of Fuel Oil Distribution, 1930, and Mineral Market Reports No. M. M. S. 415, November 19, 1935.

sold as a by-product in the competitive fuel market. Since 1926, the use of fuel and furnace oil for domestic and commercial heating has gained rapidly. The distribution of gasoline, total fuel, and fuel oil heating purposes is shown in Table 13.

An analysis of the above table shows a doubling of gasoline consumption since 1926 and a trebling of oil used for heating, while the distribution of total fuel oil showed no net gain. Gasoline consumption, however, reached a peak of 398,000,000 barrels in 1931 and did not exceed this record of consumption again until 1935. In spite of increasing automobile traffic, it is not likely that gasoline consumption will show the same rate of growth in the coming year as was shown up to 1931. The petroleum industry is, therefore, giving increasing attention to heating oils as an additional source of income.

This program is not without its market difficulties. Since not all fuel oil can be converted into a product suitable for heating oils, an increasing supply of the latter can be obtained only by increasing runs of crude oil to stills. During a severe winter such as was experienced in 1935-1936, there was a heavy drain on furnace oil stocks to the extent that not only were these supplies depleted but some refineries increased runs to stills in order to meet demands for heating oils, with a concurrent increase in gasoline stocks. At the same time automobile transportation was curtailed during the cold season so that gasoline stocks early in 1936 rose considerably above a normal supply. In view of the low stocks of furnace oil at the end of the heating season of 1935-1936, there has been a tendency to increase runs to stills in order to build up a supply of furnace oil for the coming heating season in 1936-1937. If this is done, there is a possibility of increasing gasoline stocks to a point where the price structure of both gasoline and crude oil may be endangered. The increasing importance of furnace oil as a supplemental cash crop to the oil industry therefore presents a dilemma to the refining industry. If gasoline stocks are kept down to a normal level, the supply of furnace oil may be inadequate and rising prices of the latter will bring about a return to coal as a source of domestic fuel. An attempt to maintain adequate supplies of heating oil may weaken the price of gasoline. It has been suggested that an economic balance between these two products can be maintained by cracking less gas oil for gasoline than has been customary in the past, diverting it instead to heating oil use.[1]

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[1] Lamp, October 1936, p. 4.

BUILDING INDUSTRY

Illinois produces a wide variety of mineral products, including sand and gravel, cement, clay products, lime, glass sand, crushed stone, rubble and rip-rap, all of which share in construction and building activities. Although these materials do find their way into markets other than construction, the large proportion of them directly or indirectly enter into the erection of homes, offices, public buildings, and industrial structures, making these materials more or less dependent upon the extent of building activity.

TABLE 14.—VALUE OF BUILDING PERMITS IN 16 ILLINOIS CITIES AND ST. LOUIS, MISSOURI (a)

City	1933	1934	1935 (Preliminary)
Aurora	$ 104,966	$ 282,282	$ 250,270
Bloomington	192,570	238,046	579,022
Chicago	3,683,960	7,727,351	12,936,409
Cicero	56,165	162,885	198,240
Decatur	157,605	577,640	588,102
E. St. Louis	212,742	265,498	869,123
Elgin	105,953	169,946	217,945
Evanston	402,600	741,700	947,750
Freeport	102,782	99,887	230,135
Moline	102,685	170,653	335,893
Oak Park	122,940	181,850	626,200
Peoria	1,891,320	910,987	1,791,342
Quincy	73,954	58,314	81,716
Rockford	117,720	227,300	347,065
Rock Island	186,426	322,892	332,906
Springfield	535,929	326,184	456,453
St. Louis, Missouri	10,106,632	4,998,453	11,355,867
Total	$18,156,949	$17,461,868	$32,144,438

[a] Data from Commercial and Financial Chronicle

TABLE 15.—COMPARISON OF BUILDING ACTIVITY IN 811 U. S. CITIES, 1934–1935[a]

Class of Construction	Number of buildings			Estimated Cost		
	1935	1934	P. C. change	1935	1934	P. C. change
New residential	53,058	21,773	+143.7	$291,227,231	$107,146,264	+171.8
New Non-residential	79,439	64,546	+ 23.1	316,730,227	215,402,856	+ 47.0
Additions, alterations, repairs	317,626	264,241	+ 20.2	228,546,659	168,505,689	+ 35.6
All construction	450,123	350,560	+ 28.4	836,504,117	491,054,809	+ 70.3

[a] Data from U. S. Department of Labor.

The first pronounced measure of building recovery was in 1935, as shown in Table 14. An 84 per cent increase in building permits issued in the 16 Illinois cities and St. Louis, Missouri, over the 1934 total is gratifying not only in that it marks a definite upturn for the severely deflated construction industries but in that the value of building permits of this group of cities is 14.3 per cent above the average for 811 cities throughout the United States, as compiled by the U. S. Department of Labor, shown in Table 15.

Most important in Table 15 is the significant increase in new residential construction. This class of construction acts as a business barometer and is important because of its greater relative volume in normal times, and in that it is a measure of public purchasing power and a reflection of the confidence of private capital.

It must be remembered, however, that although building activity in 1935 was substantially greater than in the previous year, the total value for 1934 as given in Table 15 was actually less than in 1933. This was particularly due to the decline of almost 50 per cent in value of permits issued in St. Louis, most of the cities showing somewhat of an increase.

The building industry usually contracts more of the durable or capital goods classification than do other industries and its advance after the worst effects of a depression is usually tardy. The striking improvement now recorded is highly important for this reason. The building industry in Illinois began its decline in 1926 and reached the lowest level of activity in 1932. In 1934 many cities showed an increase and in 1935 all cities recorded in Table 14, with two exceptions, evidenced improvement.

TABLE 16.—VALUE OF BUILDING PERMITS OF SIX GROUPS OF ILLINOIS CITIES FROM 1920 TO 1935
(In millions of dollars)

Year	Chicago, Oak Park, Evanston, Cicero	St. Louis and East St. Louis	Rock Island and Moline	Rockford and Freeport	Elgin and Aurora	Springfield Decatur, Bloomington, Peoria
1920	79.5	19.6	...	...	...	9.3
1921	135.6	18.0	...	...	...	8.1
1922	243.7	27.9	...	...	...	11.2
1923	351.3	44.3	2.1	4.8	4.7	10.1
1924	316.9	43.1	2.2	4.9	4.4	15.3
1925	382.9	60.1	2.3	7.4	7.2	17.9
1926	386.9	44.3	2.6	6.5	7.7	16.4
1927	378.0	47.7	3.4	8.2	4.7	14.0
1928	338.3	45.5	2.8	7.7	5.7	13.2
1929	216.2	29.8	4.4	6.2	3.7	11.9
1930	84.6	18.8	2.1	3.5	2.2	9.3
1931	48.5	17.7	1.2	.9	1.8	5.4
1932	4.8	4.6	.3	.9	.3	1.5
1933	4.3	10.3	.3	.2	.2	2.8
1934	8.8	5.3	.5	.3	.5	2.1
1935	14.7	12.2	.7	.6	.5	3.4

Table 16 presents building permit data for six groups of Illinois cities, in millions of dollars, for the years 1920 to 1935. These figures suggest that the building industry in this State is definitely on the up-turn after having experienced its lowest level in the year 1932 of the industrial depression. Also pictured by this table are the great strides construction must take before it can be said that normal building and industrial conditions are restored. This fact is further substantiated when the 1935 total value of permits issued in these cities, $32,144,438, is compared to the total of $415,526,483 in 1928. While it is improbable that the activity of building in the period 1926-1928 will recur in the future, the level of building activity in 1935 is probably much below normal requirements.

F. W. Dodge figures[1] show that in 1935 industrial building increased slightly over that of 1934 for 37 states east of the Rocky Mountains, although it lagged as compared to an almost double outlay for residential construction in 1935. Public works and utility project contracts declined somewhat from 1934. A few building permits statistics compiled by the F. W. Dodge Corporation illustrate the importance of residential building for the improvement last year (Table 17).

TABLE 17.—VALUE OF BUILDING PERMITS FOR 37 STATES EAST OF ROCKY MOUNTAINS[a]

Class	1935	1934	1933	1931 and 1929
Residential	$478,843,100	$248,840,100	$249,262,100	$811,338,700 (1931)
Non-residential	675,488,600	543,031,800	403,723,700	2,590,221.000 (1929)
Public works	578,541,800	625,044,500	....	....
Utility	111,671,400	126,192,000	....	....

[a] Data compiled by F. W. Dodge Corporation.

A further refinement of residential construction data for 811 identical cities has been compiled by the U. S. Department of Labor and is shown in Table 18. In 1935 there was a greater number of dwellings and more money outlaid for the one-family dwelling than for any other kind. However, the greatest increase over the 1934 dwelling construction total took place in the multi-family class, showing that business conditions are returning to the point where it is profitable to relieve the shortage in apartments.

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[1] Commercial and Financial Chronicle, Jan. 27, 1936.

Table 18.—Number of Family-Dwelling Units Provided in 811 Cities[a]

Unit	No. of new buildings for which permits issued			Families provided for		
	1935	1934	P. C. Change	1935	1934	P. C. Change
One-family	49,001	20,198	+142.6	49,001	20,198	+142.6
Two-family	2,428	1,176	+106.5	4,544	2,180	+108.4
Multi-family	1,523	341	+346.6	22,970	7,290	+215.1
All kinds	52,952	21,715	+143.8	76,515	29,668	+157.9

[a] Data from U. S. Department of Labor.

Total construction awards during the first two months of 1936 were 98.5 per cent higher than for the same two months of 1935 in 37 states east of the Rocky Mountains, according to F. W. Dodge figures. Table 19 gives comparative figures for the different classes of construction for this period.

Table 19.—Construction Contracts Awarded in 37 States East of the Rocky Mountains, Comparing the First Two Months of the Years 1936 and 1935[a]

January and February	No. of Projects	New floor space (Sq. ft.)	Valuation (Dollars)	P. C.[b] increase over 1935
1936				
Residential building	6,943	19,420,000	68,615,000	75.7
Non-residential	5,116	27,431,400	153,090,700	114.1
Public works and utilities	2,107	1,057,700	125,137,300	73.2
Total construction	14,116	47,910,000	346,843,000	98.5
1935				
Residential building	5,864	10,096,900	39,027,000	....
Non-residential	4,875	10,607,300	63,571,200	....
Public works and utilities	1,854	211,200	72,222,800	....
Total construction	12,593	20,915,400	174,821,000	....

[a] Figures from the F. W. Dodge Corporation.
[b] Calculated.

The value of building permits for 16 Illinois cities for the first seven months in 1935 and 1936 has been compiled from monthly issues of the Illinois Journal of Commerce. The results are given in Table 20 which affords a basis of comparison for construction in Illinois in the year 1935 and the possible trend building may take during the remainder of the current year.

TABLE 20.—VALUE OF BUILDING PERMITS IN 16 ILLINOIS CITIES[a], BY MONTHS, 1935–1936

Month	1935			1936		
	Value of Building Permits	Number of Permits	Average Value of Permit	Value of Building Permits	Number of Permits	Average Value of Permit
January.....	$ 94,963	151	$ 628.80	$ 809,143	203	$3,985.90
February....	165,307	222	744.60	214,525	141	1,230.60
March......	704,078	379	1,857.70	974,588	632	1,542.00
April.......	790,493	601	1,315.20	3,510,586	752	4,668.00
May........	362,406	610	594.10	1,516,786	982	1,545.10
June........	686,543	629	1,091.50	1,027,920	1,077	954.40
July........	526,791	646	815.50	1,058,057	828	1,277.50

[a] The 16 cities: Aurora, Bloomington, Champaign, Danville, Decatur, East St. Louis, Elgin, Freeport, Joliet, Moline, Peoria, Quincy, Rockford, Rock Island, Springfield, and Waukegan.

CLAY PRODUCTS INDUSTRY

The clay products industry is one of the largest non-fuels mineral industries in Illinois, in terms of value of production. The total value of clay products in Illinois continued to increase in 1935, the preliminary total being $6,820,145 for this year, in comparison with $5,945,199 for the year 1934. However, the following table shows that this increase was principally in the pottery division of the industry and that there was but a slight increase in the structural and refractory clay products division.

Table 21.—Value of Clay Products, 1932 to 1935

	1932	1933	1934	1935
Structural and refractory clay products	$2,504,610	$2,328,556	$4,498,960	4,555,624
Pottery	1,837,033	1,816,467	1,446,239	2,264,521
Total	$4,341,643	$4,145,033	$5,945,199	$6,820,145

The index values of structural and refractory clay products, pottery, and building permits in Illinois are compared in figure 1 for the period 1920 to 1935. The index numbers are based on the 1923-1925 average for each unit. The close relationship between the value of clay products and the trend of building permits is clearly shown. Building permit data for the years 1920-1922 are not available.

The merely slight increase in the structural and refractory clay products division was largely the result of almost a 50 per cent reduction in production value of paving blocks in 1935. There was also a slight decrease in value of refractory cement and in non-clay refractories. The figures given in Table 22 show an increase over the 1934 totals in the following classes: common brick, face brick, hollow brick, hollow building tile, drain tile, fireclay products, and clay sold (raw or prepared). The value of those classes included under other clay products (except pottery) which decreased in 1935 includes terra cotta, sewer pipe, flue lining and non-clay refractories. Wall coping was the only product included in this category which showed an increase in 1935 over 1934.

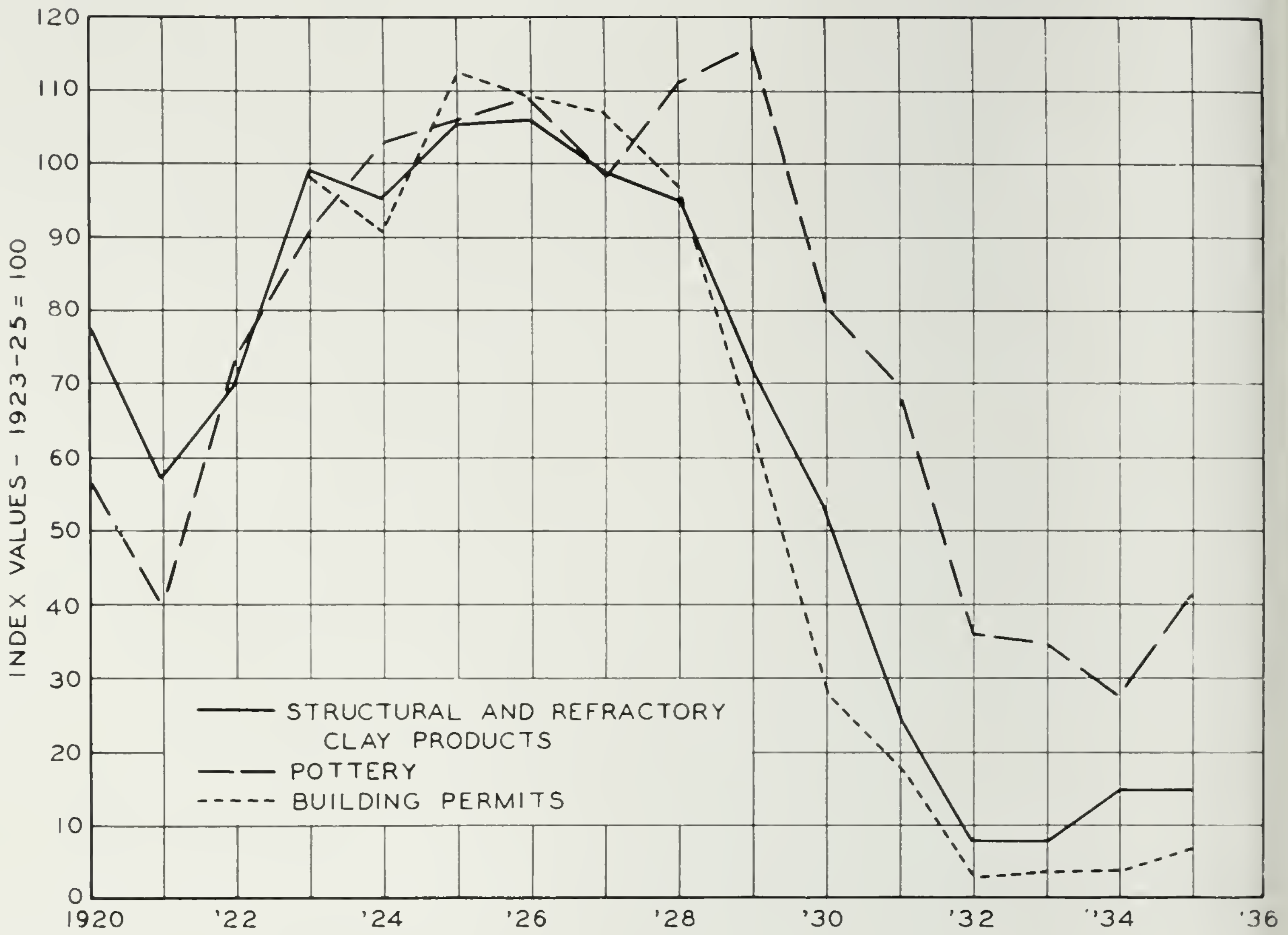

Fig. 1.—Comparative Values of Structural Clay Products, Pottery, and Building Permits. Index Numbers Based on 1923-1925 Average.

Table 22.—Production of Clay Products, by Classes, 1935

Class	Quantity	Value	Quantity Stocks on hand Dec. 31, 1935
Common brick (M)	93,435.4	$778,086.94	63,367.6
Face brick (M)	34,945.4	479,118.76	17,508.6
Hollow brick (M)	2,778.8	53,916.50	680.1
Hollow building tile (Tons)	46,624.8	198,119.68	34,057.1
Vitrified brick or block			
for paving (M)	6,411	104,171.77	4,188.6
for other purposes (M)	977	53,245.89	1,110.7
Drain tile (Tons)	38,757.4	249,589.07	13,971.6
Fireclay products	....	750,284.42	....
Refractory cement (Clay) (Tons)	175	7,822.67	21
Clay sold, raw or prepared (etc.)	....	160,429.10	....
[a]Other clay products (except Pottery)	....	1,720,839.58	....
Pottery	....	2,264,520.97	....

[a] Terra Cotta, sewer pipe, flue lining, wall coping, and non-clay refractories included under "Other clay products, except Pottery."

The production quantity, value, and stocks on hand of common brick, face brick, hollow building tile, and drain tile for the year 1935 are grouped by producing districts in Table 23. The counties in each district are as follows:

District	*Counties*
Chicago	Lake, Cook, and Will
Northern Illinois	Bureau, Fulton, Knox, LaSalle, Livingston, and Tazewell
Central and Western Illinois	Henry, Macon, Menard, and Sangamon
East St. Louis	Madison and St. Clair
Other	Other

In Table 23 those districts in which less than three producers reported are combined.

TABLE 23.—PRODUCTION OF CERTAIN TYPES OF CLAY PRODUCTS, BY DISTRICTS, 1935

District	Quantity (Thousands)	Value (Dollars)	Quantity Stocks on hand (Thousands)
Common Brick			
Chicago	68,099.3	504,080.50	48,762.3
Northern Illinois	11,079.4	122,869.84	5,712.5
Central and Western Illinois	3,142.6	32,441.60	4,678.4
East St. Louis	6,798.1	71,087.00	3,013.4
Other	4,316.0	47,608.00	1,192.0
Total	93,435.4	778,086.94	63,367.6
Face Brick			
Northern Illinois	14,656.4	223,440.53	6,681.9
Central and Western Illinois and East St. Louis	15,561.0	190,339.23	7,846.7
Other	4,728.0	65,339.00	2,998.0
Total	34,945.4	479,118.76	17,508.6
Hollow Building Tile			
	(Tons)		(Tons)
Northern Illinois	5,856.0	23,525.96	10,992.3
Central and Western Illinois and East St. Louis	17,421.8	66,778.09	3,705.3
Chicago and Other	23,347.0	107,815.63	19,359.5
Total	46,624.8	198,119.68	34,057.1
Drain Tile			
	(Tons)		(Tons)
Northern Illinois	16,913.9	116,770.71	2,533.9
Central and Western Illinois	6,745.0	45,762.12	2,208.0
East St. Louis and Other	15,098.5	87,056.24	9,229.7
Total	38,757.4	249,589.07	13,971.6

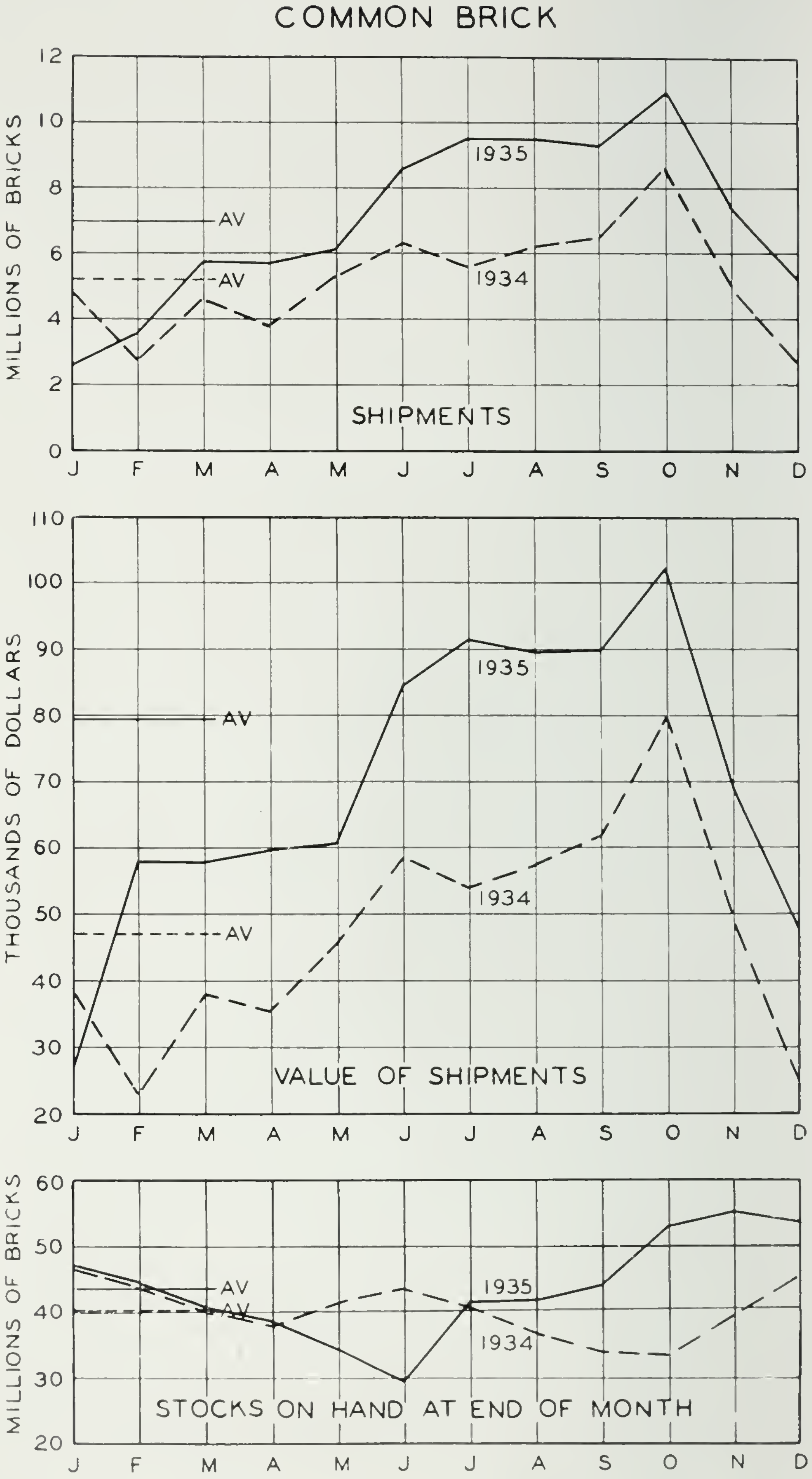

Fig. 2.—Common Brick in Illinois—Shipments, Value of Shipments, and Stocks on Hand at End of Month, for 1934-1935.

Table 24 presents data compiled from the Bureau of Census statistics from selected identical plants for the years 1932 to 1935. Total shipments, value of shipments, monthly averages, average values per unit, and stocks on hand December 31 of each year are given for common brick, face brick, and hollow building tile.

TABLE 24.—SHIPMENTS OF COMMON BRICK, FACE BRICK, AND HOLLOW BUILDING TILE IN ILLINOIS, 1932–1935[a]

Year	Shipments		Value		Average value per Thousand	Stocks on hand at end of year Thousands
	Total Thousands	Average per month Thousands	Total Dollars	Average per month Dollars		
Common Brick						
1932	56,388	4,699	446,906	37,242	7.93	69,771
1933	51,011	4,251	403,813	33,651	7.92	58,993
1934	62,269	5,189	564,164	47,014	9.06	55,120
1935	84,085	7,007	835,775	69,648	9.94	63,283
Face Brick						
1932	32,439	2,703	464,398	38,700	14.31	46,668
1933	22,825	1,902	305,168	25,432	13.81	26,863
1934	24,657	2,055	409,532	34,128	16.61	23,281
1935	36,923	3,077	596,248	49,687	18.85	24,411
Hollow Building Tile						
1932	30,930	2,578	104,922	8,744	3.39	45,282
1933	16,585	1,382	65,615	5,468	3.96	39,519
1934	31,580	2,632	163,312	13,609	5.17	34,766
1935	21,978	1,832	131,370	10,948	5.98	28,757

[a] Data from U. S. Bureau of Census.

In the year 1933 each item listed under common brick and face brick decreased in comparison to the corresponding figure for 1932. The greatest comparable decrease took place in face brick. Likewise, with the exception of stocks, each figure for these two types of brick increased in both 1934 and 1935, the 1935 totals in each case being greater than those of 1932. Not since 1932 has the total value of face brick shipments been greater than those of common brick, and it is yet lagging considerably.

A comparison of the data on hollow building tile with that of common and face brick gives quite a different picture. The trend in shipments and value of shipments in all three commodities is similar for the first three years, being downward in 1932 and upward in 1933, but in 1935 the tile trend falls again while the brick trend rises very markedly. This may be in part due to a natural decrease in demand for tile in 1935 or to the steady increase in value per unit placed on

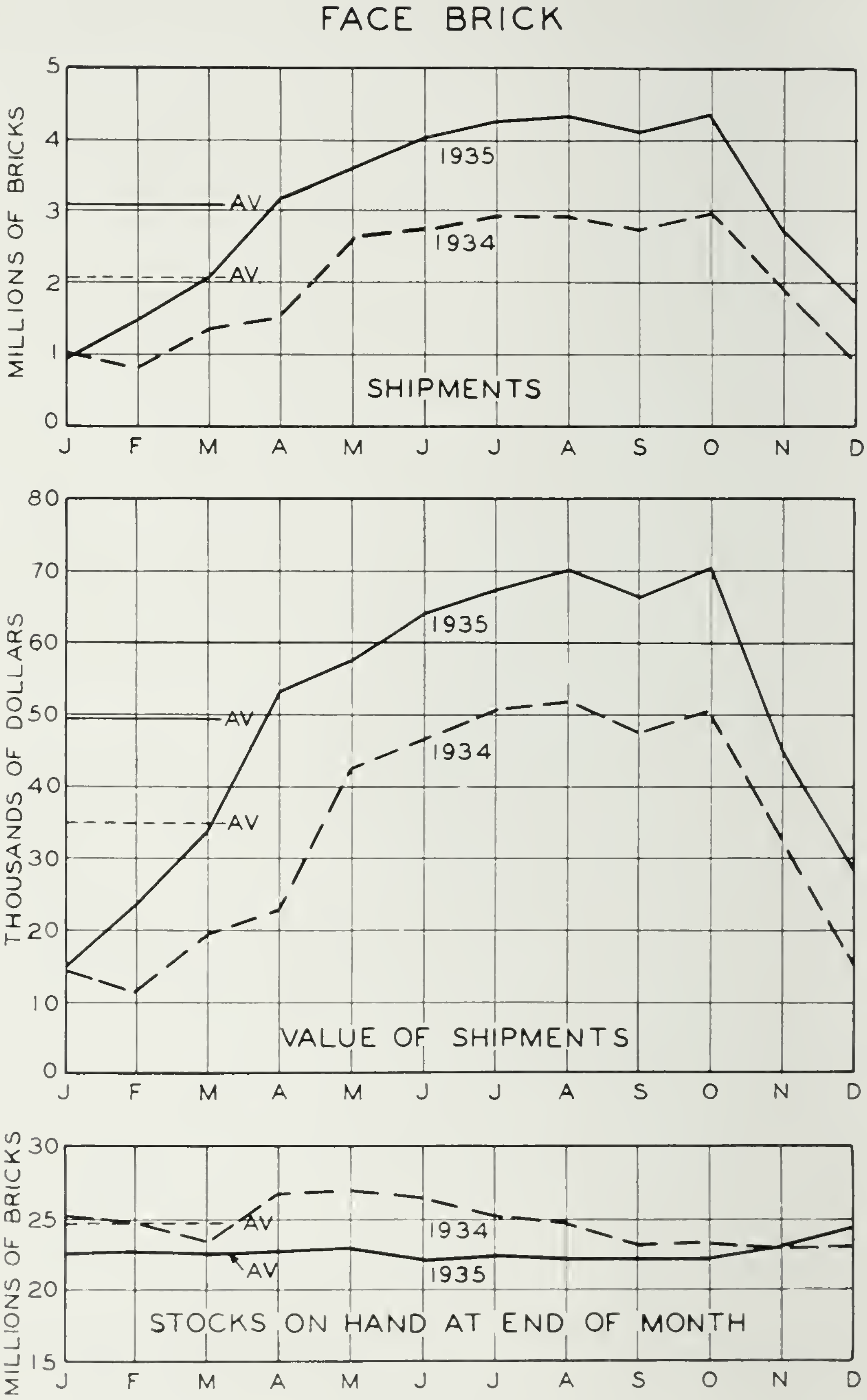

Fig. 3.—Face Brick in Illinois—Shipments, Value of Shipments, and Stocks on Hand at End of Month, 1934-1935.

hollow building tile each year since 1932. The average value for both kinds of brick fluctuated with demand during these years.

It is important to note that stocks in both common and face brick increased in 1935 for the first time. This suggests that heavy inventories have been reduced to a more normal level. Stocks of hollow building tile on hand necessarily continued to decrease in 1935. The stocks of tile on hand at the end of the year were still greater than the total shipped during 1935. However, the stocks have shrunk 37 per cent from the 1932 total.

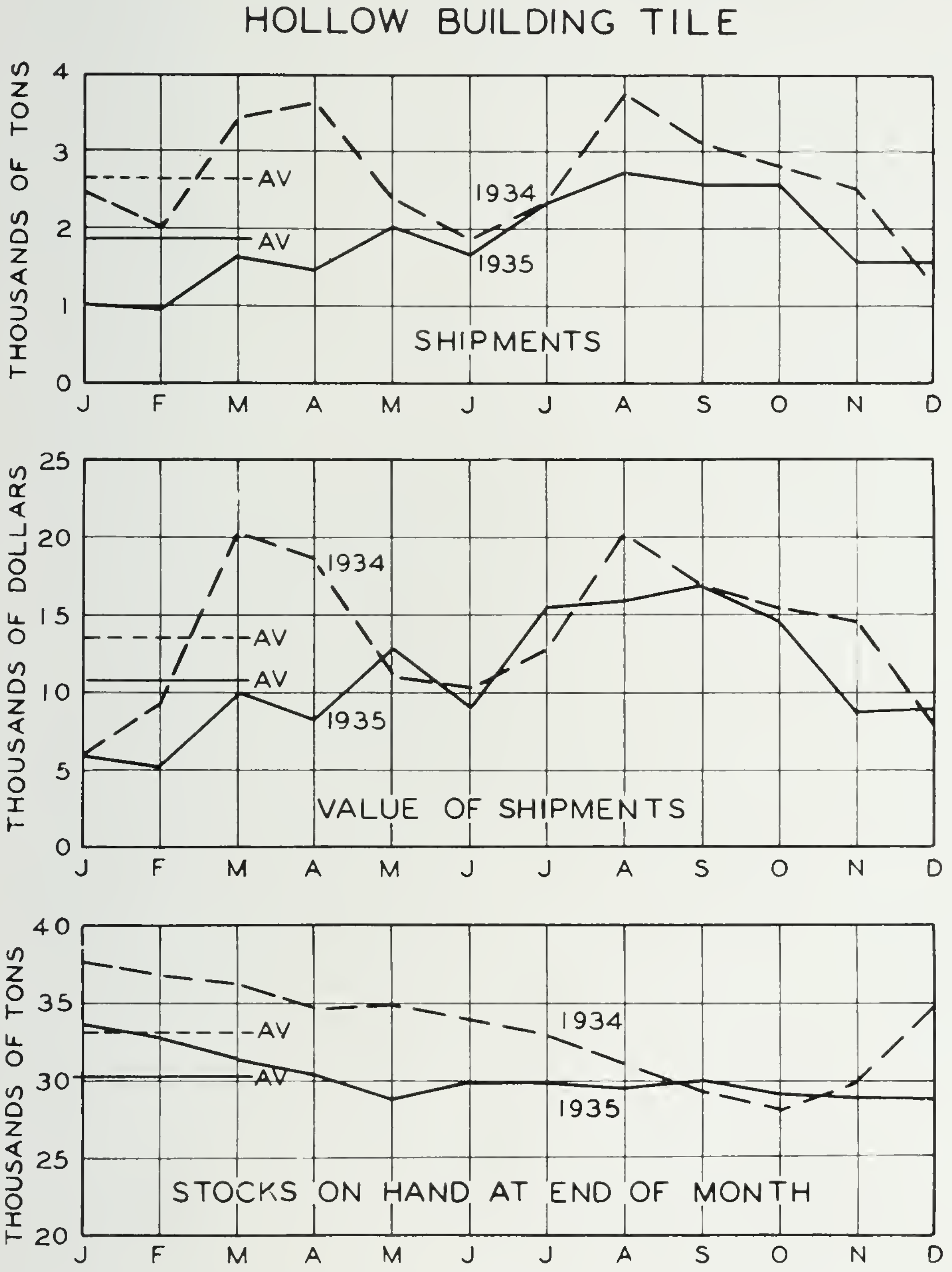

Fig. 4.—Hollow Building Tile in Illinois—Shipments, Value of Shipments, and Stocks on Hand at End of Month, 1934-1935.

The trends of shipments by months during the years 1934 and 1935 are given for common brick, face brick, and hollow building tile in figures 2, 3, and 4. The monthly averages for each year are given for comparison.

The important part that the stocks on hand play in the economic picture is not the actual number or quantity but the relation of the quantity of stocks to the demand. The producer can determine the size of the stocks he should carry on hand to meet emergencies only through past experience. Probably the most pertinent data available to judge future demands are shipments of the past year, with an analysis of the probable increase or decrease in demand for the coming months. Table 25 shows the relation of stocks on hand at the end of each year to the demand for that current year in terms of month's supplies on hand, December 31.

TABLE 25.—SUPPLY OF STOCKS ON HAND AT END OF YEAR, IN TERMS OF MONTHS, 1932–1935

Year	Common Brick (Months)	Face Brick (Months)	Hollow Building Tile (Months)
1932	14.8	17.3	17.6
1933	13.9	14.1	28.6
1934	10.6	11.3	13.2
1935	9.0	7.9	15.7

The actual quantity of stocks on hand as seen in Table 24 was increased for both common and face brick in 1935. However, the ratio of these stocks to current demand has continued to decrease through 1935 and will continue to do so until this portion of the industry is stabilized. The stocks of hollow building tile on hand at the end of each year, as seen in Table 24, has in no way coincided with demand and at the present time is no doubt much larger than that necessary to meet adequately the current requirements.

Detailed statistics for the shipments of common brick, face brick, and hollow building tile during the year 1935 are given in Table 26. Similar tables are given for the years 1932, 1933, and 1934 in Illinois Geological Survey Report of Investigations 39.

TABLE 26.—SHIPMENTS OF COMMON BRICK, FACE BRICK, AND HOLLOW BUILDING TILE IN ILLINOIS IN 1935

Month	Number of Plants	Shipments		Thousands stocks on hand at end of month
		Thousands	Value	
		Common Brick[a]		
January	34	2,636	$25,941	56,863
February	35	3,568	57,938	54,359
March	35	5,790	57,938	51,443
April	34	5,754	59,476	48,538
May	35	6,139	60,671	44,451
June	35	8,537	84,102	39,338
July	34	9,463	91,483	51,104
August	32	9,483	89,538	51,241
September	31	9,319	89,824	53,927
October	31	10,864	102,321	62,679
November	31	7,346	68,933	65,065
December	32	5,185	47,610	63,283
		Face Brick[a]		
January	18	942	$14,993	22,745
February	18	1,492	23,398	22,814
March	17	2,060	33,606	22,739
April	17	3,205	53,247	22,793
May	17	3,605	57,594	23,046
June	17	4,037	64,168	22,293
July	17	4,271	67,589	22,584
August	17	4,341	70,117	22,407
September	17	4,106	66,798	22,433
October	17	4,361	70,796	22,360
November	17	2,775	45,358	23,076
December	17	1,728	28,584	24,411
		Hollow Building Tile[a]		
		(Tons)		(Tons)
January	16	1,001	$ 5,993	33,593
February	16	929	5,353	32,856
March	15	1,613	9,996	31,484
April	15	1,476	8,266	30,404
May	15	2,054	12,743	28,764
June	15	1,648	9,006	29,937
July	15	2,308	15,502	29,814
August	15	2,718	15,749	29,562
September	15	2,560	16,766	30,090
October	15	2,568	14,614	29,091
November	15	1,555	8,607	28,827
December	15	1,548	8,775	28,757

[a] Source: Monthly report on "Structural Clay Products," Bureau of Census.

A comparison of shipments of these three classes of clay products in Illinois are given, by totals, for the first six months of 1935 and 1936, as follows:

Table 27.—Shipments of Common Brick, Face Brick, and Hollow Building Tile in Illinois for Six Months, 1935–1936

Average Number of Plants Reporting		Shipments in Thousands		Value of Shipments		Stock on Hand June 30, in Thousands	
1935	1936	1935	1936	1935	1936	1935	1936
Common Brick							
35	32	32,424	66,388	$347,066	$649,317	39,338	60,083
Face Brick							
17	17	15,341	31,591	$247,006	$527,233	22,293	23,925
Hollow Building Tile							
		(Tons)				(Tons)	
15	15	8,721	20,032	$ 51,357	$109,576	29,937	35,333

PORTLAND CEMENT

Portland cement shipped from mills in Illinois in 1935 amounted to 3,273,000 barrels. Value of the product was $4,625,000 with a value per barrel increase to $1.41. (Table 28). Consumption of Portland cement by months for 1933-1935 is shown in Table 29.

Table 28.—Shipments of Cement, in Barrels, Value, and Consumption in Illinois 1928–1935[a]

Year	Shipments	Value	Average factory value per barrel	Consumption
1928	7,405,667	$11,602,848	$1.57	17,683,269
1929	7,738,208	11,134,538	1.44	13,490,520
1930	7,951,680	10,519,162	1.32	11,164,248
1931	6,425,909	5,342,446	0.83	7,925,435
1932	5,829,687	3,446,482	0.59	5,822,358
1933	4,193,048	4,607,335	1.08	5,281,216
1934	3,907,000	5,489,000	1.40	5,008,440
1935	3,273,000	4,625,000	1.41	4,932,873

[a] United States Bureau of Mines, Monthly Cement Statement No. 177.

Table 29.—Portland Cement Consumption in Illinois, 1933–1935
(In barrels)[a]

Month	1933	1934	1935
January	71,367	133,420	133,855
February	115 629	99,658	159,240
March	125,846	183,486	304,977
April	171,203	386,683	352,243
May	177,861	671,643	414,792
June	347,314	557,475	460,779
July	1,124,429	512,159	675,717
August	996,408	545,571	701,896
September	881,269	546,926	627,998
October	665,137	736,326	613,827
November	295,027	476,070	304,021
December	309,726	158,940	183,527
Total	5,281,216	5,008,357	4,932,873

[a] United States Bureau of Mines, Monthly Cement Statements.

FLUORSPAR[1]

Fluorspar shipments from the Illinois-Kentucky area continued to increase in response to expanding needs of the steel industry.

Consumption of fluorspar at steel mills increased 19,700 short tons in 1935 compared with 1934, due to accelerated activity that brought the operating rate of the steel industry from 37 per cent of capacity in 1934 to 49 per cent in 1935. Both domestic producers and importers shared this increased business; in fact, total sales of fluorspar to the steel industry were the largest since 1930, and the sales by domestic producers exceeded those of any year since 1929.

Purchases of 12,225 tons of fluorspar by glass manufacturers in 1935 were the largest on record. Sales to enamel and hydrofluoric acid plants increased 1,800 and 400 tons, respectively, from 1934, and consumption of acid-grade fluorspar as a raw material in the manufacture of refrigerants was 61 per cent greater.

Total sales of fluorspar to consumers in the United States in 1935 were 137,867 short tons, of which 123,561 tons were from domestic mines and 16,306 tons were imported, compared with a total of 101,662 tons in 1934, of which 85,264 tons were from domestic mines and 16,398 tons were imported.

Despite the improved demand for fluorspar in 1935, the selling price by producers was lower than in 1934. For example, the average selling price of fluxing-gravel fluorspar dropped from $15.28 a ton f.o.b. Illinois-Kentucky mines in 1934 to $13.76 a ton in 1935. The average selling price of all grades declined from $16.22 a short ton in 1934 to $15.04 in 1935.

Other noteworthy developments in 1935 were the substantial reduction in the stocks of fluorspar in the hands of producers, the high level of shipments from Kentucky which have been exceeded only in 1918, 1928, and 1929, and the movement of fluorspar from Colorado to eastern markets.

Tables 30, 31, and 32 show the details of the shipments of flourspar by States, by kinds, and by uses in 1934 and 1935.

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[1] Data from U. S. Bureau of Mines, Minerals Yearbook, pp. 963-979.

Table 30.—Fluorspar Shipped from Mines in Illinois and Kentucky 1934–1935

State	1934			1935		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Illinois	33,234	$567,396	$17.07	44,120	$685,794	$15.54
Kentucky	43,163	690,990	16.01	68,679	1,017,451	14.81
Other states	9,389	133,019	.....	10,762	155,089	.....
Total	85,786	1,391,405	16.22	123,561	1,858,334	15.04

Table 31.—Fluorspar Shipped from Mines in the United States, 1934–1935, by Kinds

Kind	1934			1935		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Gravel	74,249	$1,121,974	$15.11	105,280	$1,452,733	$13.80
Lump	3,101	60,135	19.39	5,268	101,578	19.28
Ground	8,436	209,296	24.81	13,013	304,023	23.36
Total	85,786	1,391,405	16.22	123,561	1,858,334	15.04

Table 32.—Fluorspar Shipped from Mines in the United States, 1934–1935, by Uses

Use	1934			1935		
	Short tons	Value		Short tons	Value	
		Total	Average		Total	Average
Steel	70,672	$1,061,864	$15.03	100,988	$1,390,357	$13.77
Foundry	1,489	23,807	15.99	2,336	29,068	12.44
Glass	7,343	167,182	22.77	10,256	227,917	22.22
Enamel and vitrolite	2,590	67,849	26.20	4,087	100,686	24.64
Hydrofluoric acid and derivatives	1,666	35,708	21.43	3,333	74,732	22.42
Miscellaneous	1,504	26,393	17.55	2,248	30,923	13.76
Exported	522	8,602	16.48	313	4,651	14.86
Total	85,786	1,391,405	16.22	123,561	1,858,334	15.04

Stocks at mines.—The stocks of fluorspar at mines or at shipping points on December 31, 1935, were 60,752 short tons, a decrease of 28 per cent. These stocks consisted of about 27,400 tons of crude fluorspar (calculated to be equivalent to 11,800 tons of ready-to-ship fluorspar) and 33,389 tons of ready-to-ship fluorspar. The substantial decrease (about 17,200 tons) in the stocks of ready-to-ship fluorspar in 1935 and the concurrent smaller decline of about 6,000 tons in the stocks of crude fluorspar are noteworthy.

Imports.—The total imports of fluorspar for consumption in the United States in 1935 were 16,340 short tons (10,578 tons containing more than 97 per cent and 5,762 tons containing not more than 97 per cent calcium fluoride) valued at $170,049, compared with 16,705 tons (10,632 tons containing more than 97 per cent and 6,073 tons containing not more than 97 per cent calcium fluoride) valued at $183,286 in 1934. The imports were equivalent to 13 per cent of the total shipments of domestic fluorspar in 1935 compared with 19 per cent in 1934.

About 33 per cent of the imports in 1935 was metallurgical-gravel fluorspar, 19 per cent ceramic-ground fluorspar, and 48 per cent acid (chiefly lump) fluorspar. The metallurgical-gravel fluorspar was imported from Spain and Germany, chiefly Spain; the ceramic-ground fluorspar was imported chiefly from Germany, followed in order by Spain and Italy; and the acid-grade fluorspar was imported chiefly from Germany, followed in order by the Union of South Africa and Spain.

Table 33, compiled from the records of the Bureau of Foreign and Domestic Commerce, shows the imports of fluorspar into the United States by countries in 1934 and 1935.

TABLE 33.—FLUORSPAR IMPORTED INTO THE UNITED STATES, 1934–1935, BY COUNTRIES[a]

Country	1934		1935	
	Short tons	Value	Short tons	Value
Canada	187	$ 2,962	1	$ 14
China	112	990	......	......
Germany	8,224	98,565	9,843	119,275
Italy	60	587	55	589
Newfoundland	745	10,460	......	....
Spain	4,914	35,316	5,094	35,432
Union of South Africa	1,997	31,872	1,347	23,739
United Kingdom	466	2,534	......	....
Total	16,705	183,286	16,340	179,049

[a] Compiled from records of Bureau of Foreign and Domestic Commerce.

Table 34, compiled from data furnished by importers to the Bureau of Mines, shows the quantities of imported fluorspar delivered to consumers in the United States in 1934 and 1935 and the selling price at tidewater (duty paid) irrespective of the year of importation into the United States; it differs from the preceding table, which shows the quantities received in the United States during 1934 and 1935. The quantities in this table are based on the actual outturn weight ascertained by sworn weighers and represent the weight on which duty was paid and the entries were liquidated.

TABLE 34.—IMPORTED FLUORSPAR DELIVERED TO CONSUMERS IN THE UNITED STATES IN 1934 AND 1935

Industry	1934			1935		
	Short Tons	Selling Price at Tidewater, Including Duty		Short Tons	Selling Price at Tidewater, Including Duty	
		Total	Average		Total	Average
Steel	5,394	$100,830	$18.69	5,702	$102,635	$18.00
Glass	1,257	36,120	29.74	1,969	49,803	25.29
Enamel	583	17,324	29.72	920	24,447	26.57
Hydrofluoric acid	8,982	217,650	24.23	7,715	189,794	24.60
Cement	182	4,100	22.53	......	....	.....
Total	16,398	376,024	22.93	16,306	366,679	22.49

AGRICULTURAL LIMESTONE

Final returns from producers of agricultural limestone in Illinois and adjoining states show that Illinois farmers applied to their soil approximately 523,256 tons of limestone in 1935. This is a 51 per cent increase over the 1934 total consumption and is almost four times the amount used in the low year, 1932. Such an increase shows that the purchase of stone by farmers is returning rapidly to the level of pre-depression years. The following figures represent the approximate consumption of agricultural limestone in Illinois by years from 1930 to 1935.

Table 35.—Agricultural Limestone Consumed in Illinois, 1930–1935

Year	Tons
1930	811,000
1931	266,886
1932	132,995
1933	190,963
1934	346,141
1935	523,256

The most significant increase in limestone consumption was in those counties in the northeast, south, and southeastern parts of the State, Districts I and V as shown in figure 8. The very pronounced increase in District I in 1935 as shown in figure 5 is no doubt an exaggeration in part due to incomplete data for the past years.

Detailed statistics were received from Illinois producers and from producers in Indiana, Iowa, Missouri, and Wisconsin who ship agricultural limestone into Illinois. Information was also received from Farm Advisers in Illinois and from certain County Highway Engineers. Such cooperation has made the 1935 agricultural limestone data the most complete for any year to date.

The tonnage of agricultural limestone marketed in each county in Illinois during 1934 and 1935 is shown in Table 36. It has been necessary to estimate the consumption for certain counties, the figures for each representing a comparison of data received from both producers and farm advisers.

Table 36.—Tonnage of Agricultural Limestone Used in Illinois During 1934 and 1935

(Tons marketed in each county in Illinois)

County	1934 Total	1935		
		Produced in Illinois	Produced in other states	Total
Adams	7,587	5,194	......	5,194
Alexander	0	55	....	55
Bond[a]	1,769	6,146	134	6,280
Boone	1,060	0	....	0
Brown	918	432	....	432
Bureau[a]	1,046	2,964	36	3.000
Calhoun	0	0	....	0
Carroll	0	128	....	128
Cass[a]	592	936	....	936
Champaign	4,185	3,435	96	3,531
Christian	3,060	3,911	....	3,911
Clark	11,646	6,959	8,382	15,341
Clay	120	469	....	469
Clinton	7,937	16,487	45	16,532
Coles	1,532	436	474	910
Cook	2,615	14,100	....	14,100
Crawford	763	295	1,083	1,378
Cumberland	2,647	1,936	1,836	3,772
DeKalb	1,138	435	....	435
DeWitt	2,709	1,649	....	1,649
Douglas	2,177	1,601	1,119	2,720
DuPage	567	3,823	....	3,823
Edgar	3,526	1,819	2,031	3,850
Edwards	1,379	948	358	1,306
Effingham	4,200	3,264	6,659	9,923
Fayette	1,079	2,997	998	3,995
Ford	3,689	2,297	....	2,297
Franklin	2.547	3,364	....	3,364
Fulton	2,732	1,520	315	1,835
Gallatin	134	0	....	0
Greene[a]	11,046	8,739	....	8,739
Grundy	1,483	904	....	904
Hamilton	1,173	1,859	....	1,859
Hancock	2,054	952	....	952
Hardin	1,200	0	....	0
Henderson	0	115	....	115
Henry	8,889	5,327	3,248	8,575
Iroquois	5,641	2,033	2,180	4,213
Jackson	5,423	6,001	....	6,001
Jasper	614	2,179	272	2,451
Jefferson[a]	1,301	2,930	228	3,158
Jersey[a]	5,326	5,884	....	5,884
Jo Daviess[a]	102	8,000	....	8,000
Johnson	1,500	1,680	....	1,680
Kane	1,923	10,487	....	10,487
Kankakee	433	3,272	....	3,272
Kendall	2,687	1,214	....	1,214
Knox	4,796	1,233	2,612	3,845
Lake	1,237	9,353	59	9,412
LaSalle	2,339	1,304	....	1,304
Lawrence	1,524	446	1,789	2,235
Lee	614	87	61	148
Livingston	4,625	10,888	....	10,888

TABLE 36.—TONNAGE OF AGRICULTURAL LIMESTONE USED IN ILLINOIS (*Concluded*)
(Tons marketed in each county in Illinois)

County	1934 Total	1935		
		Produced in Illinois	Produced in other states	Total
Logan	1,630	2,721		2,721
McDonough	2,667	342		342
McHenry	1,224	1,962	142	2,104
McLean	31,595	20,125		20,125
Macon	3,345	2,291	289	2,580
Macoupin[a]	15,891	16,012		16,012
Madison[a]	15,364	17,396		17,396
Marion[a]	2,646	6,491	1,092	7,583
Marshall	972	2,886		2,886
Mason	2,352	2,264		2,264
Massac	0	53		53
Menard	671	5,001		5,001
Mercer	3,055	274	3,582	3,856
Monroe	16,521	9,592		9,592
Montgomery[a]	3,236	5,365		5,365
Morgan[a]	3,226	2,904		2,904
Moultrie	449	230	162	392
Ogle[a]	0	4,000		4,000
Peoria	5,670	4,617	605	5,222
Perry	4,250	10,200		10,200
Piatt	3,324	2,802	88	2,890
Pike[a]	770	20,000		20,000
Pope	1,260	116		116
Pulaski	100	64		64
Putnam	57	210		210
Randolph[a]	16,521	15,167	235	15,402
Richland	414	909	900	1,809
Rock Island	3,616	5,282	1,333	6,615
St. Clair[a]	6,362	27,076		27,076
Saline	6,186	1,003		1,003
Sangamon[a]	4,122	5,764		5,764
Schuyler[a]	170	513		513
Scott[a]	268	226		226
Shelby	1,420	2,936	495	3,431
Stark	1,303	582	822	1,404
Stephenson	900	198		198
Tazewell	3,874	3,386		3,386
Union	3,100	3,562		3,562
Vermilion	2,436	2,021	391	2,412
Wabash	1,450	190	1,337	1,527
Warren	215	0	419	419
Washington[a]	11,852	13,223	7,867	21,090
Wayne	454	456	234	690
White	2,047	703	735	1,438
Whiteside	2,166	2,124	60	2,184
Will	4,031	58,280		58,280
Williamson	1,915	1,958		1,958
Winnebago	500	14		14
Woodford	5,462	4,692		4,692
County unknown	5,798	7,782		7,782
Total	346,141	468,453	54,803	523,256

[a] Estimated.

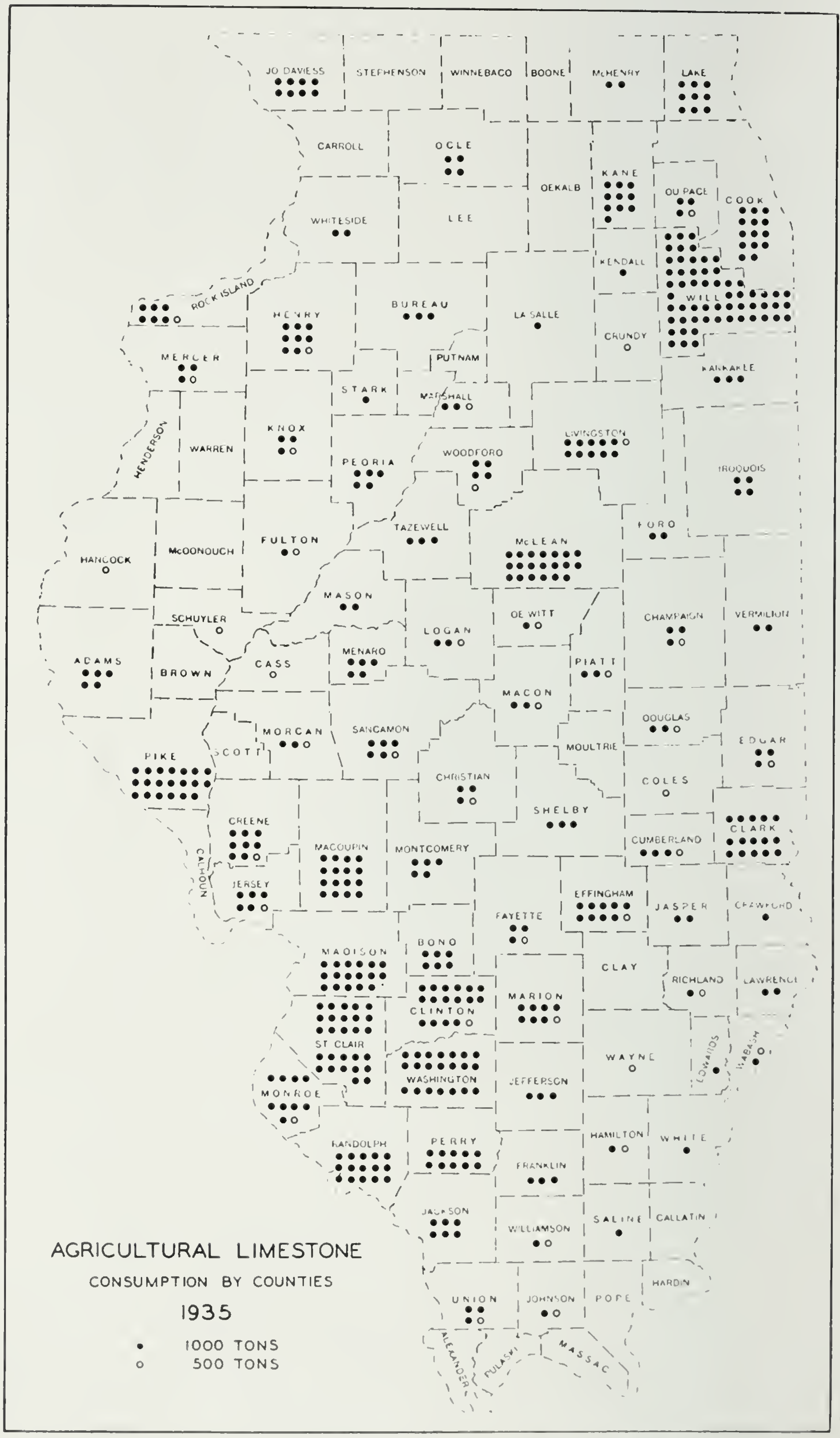

Fig. 5.—Consumption of Agricultural Limestone, By Counties, for 1935.

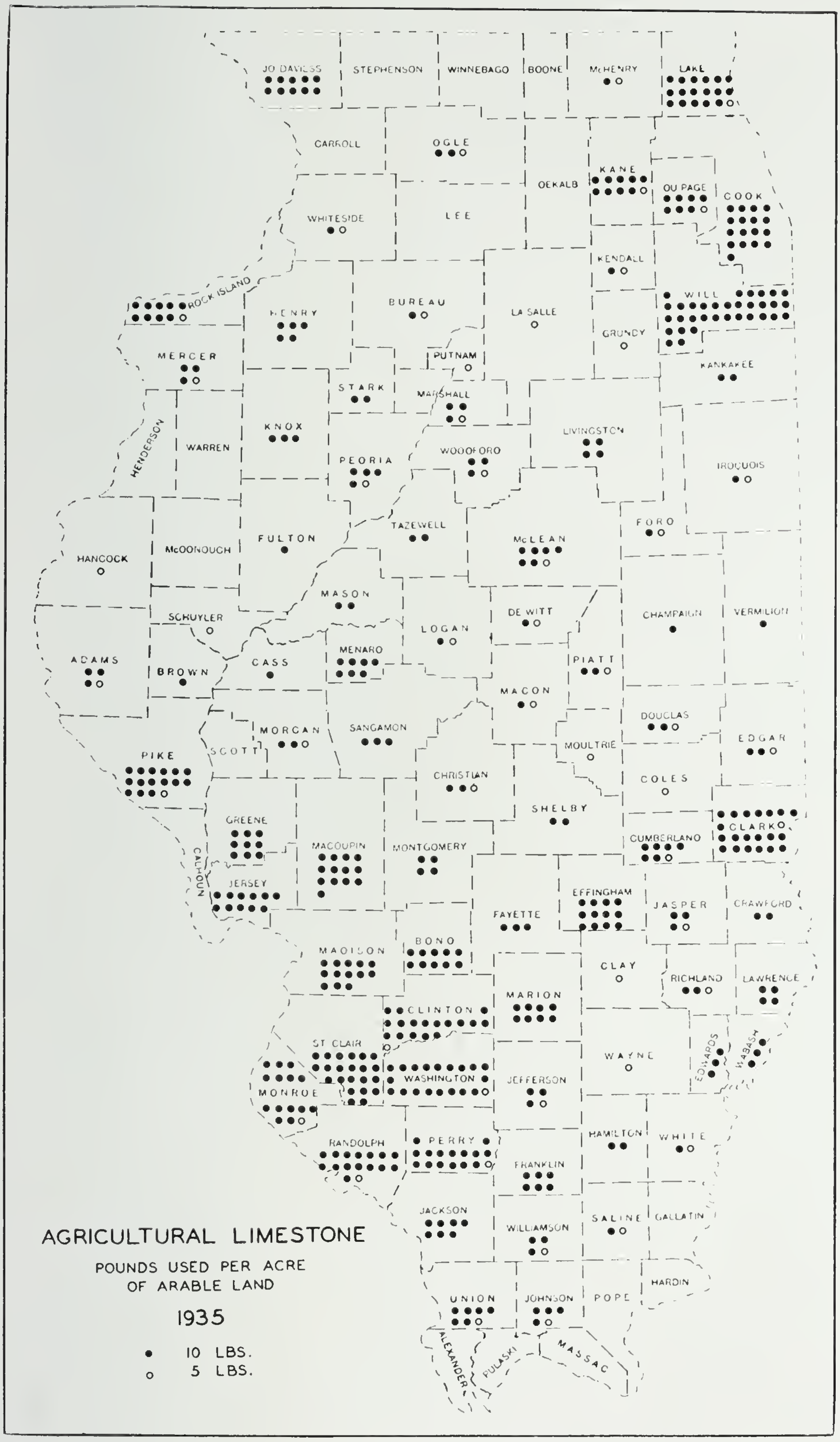

Fig. 6.—Consumption of Agricultural Limestone in Pounds Per Acre of Arable Land, By Counties, for 1935.

Figure 5 pictures the approximate total consumption of agricultural limestone in each county during 1935. The largest consuming areas are at once seen to be Districts I and IV and those counties in the western part of District V. Figure 6 shows the approximate number of pounds of limestone used per acre of arable land in each county in 1935. Detailed statistics of this data for the years 1933, 1934, and 1935 are given in Table 37.

TABLE 37.—CONSUMPTION OF LIMESTONE ON CROP LAND, BY COUNTIES
(In pounds per acre)

County	Farm land in crops (1929) Acres	Pounds of Limestone per Acre			
		1933	1934	1935	1926–1930 average
Group 1					
Cook	164,478	10	32	172	28
DuPage	102,525	18	11	75	37
Ford	251,129	10	29	19	45
Grundy	197,112	7	20	9	31
Iroquois	557,286	13	20	15	34
Kane	211,385	13	18	99	35
Kankakee	302,664	4	3	22	30
Kendall	154,130	2	35	16	43
Lake	105,632	5	24	178	19
Livingston	546,648	15	17	40	47
McHenry	222,210	5	11	19	25
Will	348,255	1	23	334	25
Average for data available		8.6	20.2	83.2	33.3
Group 2					
Boone	119,416	1	18	([a])	90
Bureau	364,803	2	9	16	41
Carroll	160,827	([a])	([a])	([a])	68
DeKalb	306,290	7	7	3	55
Henry	352,861	20	50	50	85
JoDaviess	156,735	([a])	([a])	102	48
La Salle	518,450	2	9	5	35
Lee	324,847	([a])	4	1	74
Mercer	202,377	3	30	38	61
Ogle	312,720	([a])	([a])	26	48
Rock Island	133,975	41	54	99	118
Stephenson	216,596	([a])	8	2	52
Whiteside	295,856	5	15	15	101
Winnebago	189,201	([a])	5	([a])	180
Average for data available		10.1	19	32.5	75.4

[a] Data incomplete.

Table 37.—Consumption of Limestone (*Continued*)

County	Farm land in crops (1929) Acres	Pounds of Limestone per Acre			
		1933	1934	1935	1926–1930 average
	Group 3				
Adams	277,310	([a])	55	37	59
Brown	80,291	7	23	11	108
Cass	146,012	24	8	13	91
Christian	319,031	12	19	25	46
Champaign	514,120	8	20	13	49
Clark	145,009	79	160	212	178
Coles	209,790	5	14	9	43
Cumberland	108,915	15	49	69	50
DeWitt	188,278	26	18	18	50
Douglas	205,598	6	21	26	49
Edgar	269,689	12	26	29	29
Fulton	300,163	5	20	12	27
Hancock	283,251	([a])	15	7	51
Henderson	191,106	([a])	([a])	1	49
Knox	274,189	8	35	31	46
Logan	304,439	2	11	18	36
Macon	272,508	11	25	17	33
Marshall	160,608	6	12	36	55
Mason	228,930	30	29	20	86
McDonough	230,365	2	23	3	50
McLean	587,468	14	108	69	75
Menard	141,309	9	9	71	39
Morgan	221,958	10	29	26	64
Moultrie	163,885	6	6	5	25
Peoria	216,423	16	52	48	75
Piatt	217,725	6	31	27	35
Pike	251,943	([a])	([a])	159	125
Putnam	59,772	8	2	7	78
Sangamon	368,786	7	22	31	45
Scott	91,619	9	6	3	116
Schuyler	138,184	7	2	7	36
Shelby	291,314	12	10	23	44
Stark	127,343	8	21	22	47
Tazewell	287,997	12	27	24	66
Vermilion	412,415	5	12	12	45
Warren	224,789	6	2	4	29
Woodford	238,169	14	46	39	93
Average for data available		12.3	27.7	32.0	60.0
	Group 4				
Calhoun	71,970	([a])	([a])	([a])	52
Greene	181,258	15	122	91	151
Jersey	114,569	16	93	113	198
Macoupin	272,761	26	116	132	98
Madison	267,696	105	115	130	206
Monroe	128,509	171	257	149	419
Randolph	196,678	134	168	157	250
St. Clair	245,327	138	52	220	286
Average for data available		86.4	131.8	141.7	209.9

[a] Data incomplete.

TABLE 37.—CONSUMPTION OF LIMESTONE (*Concluded*)

County	Farm land in crops (1929) Acres	Pounds of Limestone per Acre			
		1933	1934	1935	1926–1930 average
Group 5					
Alexander	49,556	([a])	([a])	2	232
Bond	126,912	15	20	99	212
Clay	163,655	1	1	6	70
Clinton	188,070	58	84	176	238
Crawford	118,315	11	13	23	145
Edwards	84,133	26	33	31	83
Effingham	164,133	28	51	121	146
Fayette	237,164	6	9	34	71
Franklin	109,587	22	47	61	95
Gallatin	98,154	6	3	([a])	47
Hamilton	154,223	11	15	24	31
Hardin	30,345	20	80	([a])	15
Jackson	164,628	43	66	73	130
Jasper	170,030	4	7	39	36
Jefferson	168,303	7	16	38	68
Johnson	73,623	3	40	46	36
Lawrence	111,798	4	27	40	57
Marion	187,582	21	27	81	82
Massac	63,905	6	([a])	1	68
Montgomery	255,255	19	25	42	103
Perry	132,068	33	64	155	123
Pope	69,469	10	36	([a])	23
Pulaski	59,876	([a])	3	2	67
Richland	128,237	6	6	28	61
Saline	115,918	53	107	18	43
Union	105,293	75	59	68	121
Wabash	91,773	14	32	33	71
Washington	214,242	154	110	197	196
Wayne	236,695	2	4	6	20
White	182,452	13	22	16	75
Williamson	111,266	24	34	35	64
Average for data available	....	23.9	35.9	53.4	91.2

[a] Data incomplete.

The trend of average consumption of agricultural limestone on crop lands, in pounds per acre, for the years 1926 to 1935 are given by districts in figure 7. This chart shows the more erratic average consumption of the southern Districts IV and V. The depression decrease in consumption began in 1930 in these two areas, while the northern areas did not decline to a marked degree until 1931. Since 1932 all five districts have shown an increase in the amount of stone applied per acre.

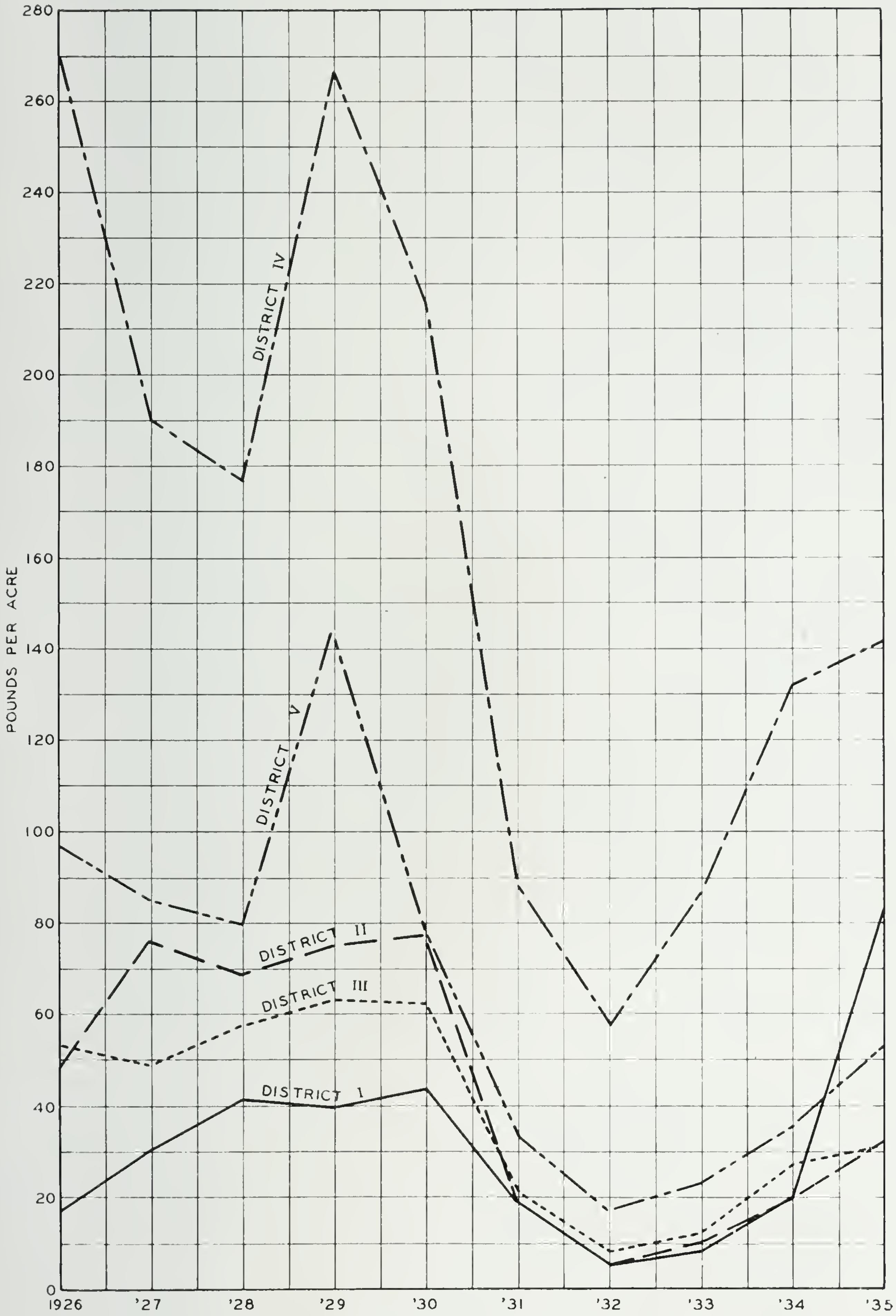

Fig. 7.—Average Consumption of Limestone on Crop Lands, in Pounds Per Acre, By Districts (See Fig. 8), 1926-1935.

The percentage of the total consumption in 1935 of limestone that was brought into Illinois from outside sources decreased from the 1934 figure (Table 38). Of this imported stone, 70 per cent came from Indiana and about 29 per cent from Iowa, only a minor amount coming from Missouri and Wisconsin.

TABLE 38.—AGRICULTURAL LIMESTONE PRODUCED IN OTHER STATES AND MARKETED IN ILLINOIS, 1931–1935
(In tons)

Year	Tons consumed from outside producers	Per cent of total consumption
1931	31,160.55	11.6
1932	15,231.	11.5
1933	12,845.	6.7
1934	56,095.	16.2
1935	54,803.	10.5

Although the total amount of agricultural limestone produced in other states and marketed in Illinois was less in 1935 than in 1934, this total is yet about three and one-half times the amount of limestone produced in Illinois and marketed in other states, as given in Table 39.

Table 39 shows the trend of Illinois limestone marketed in other states from 1931 to 1935. The yearly total has increased for the past three years but has not as yet reached the 1931 level of almost 17,000 tons.

TABLE 39.—AGRICULTURAL LIMESTONE PRODUCED IN ILLINOIS AND MARKETED IN OTHER STATES, 1931–1935
(In tons)

Year	Wis.	Iowa	Mo.	Ky.	Ind.	Mich.	Tenn.	Total
1931	650	....	37	500	9,570	4,764	1,450	16,971
1932	....	....	263	....	3,311	850	683	5,107
1933	....	62	80	41	5,299	421	730	6,633
1934	85	65	2,232	....	9,093	1,546	238	13,259
1935	67	1	130	32	10,102	4,135	1,095	15,562

OTHER NON-METALLIC PRODUCTS

The distribution and trends of production from 1933 to 1935 of structural non-metallic materials, by districts, are shown in tables 40 and 41. The districts may be identified by reference to figure 8.

Road building has been one of the major outlets for sand and gravel in the past several years. The sharp decline in building activity which began in 1927 and continued until 1934 not only reduced the market demand for these materials, but increased their dependence upon highway construction and other public works.

The market for limestone was similarly affected by the slump in building activity but, in the case of this material, a substantial market outlet is maintained in the agricultural limestone business. A close study of probable future trends in private construction as well as an analysis of future highway and public works programs are eventual in order to evaluate the future market outlook for these two groups of non-metallic minerals.

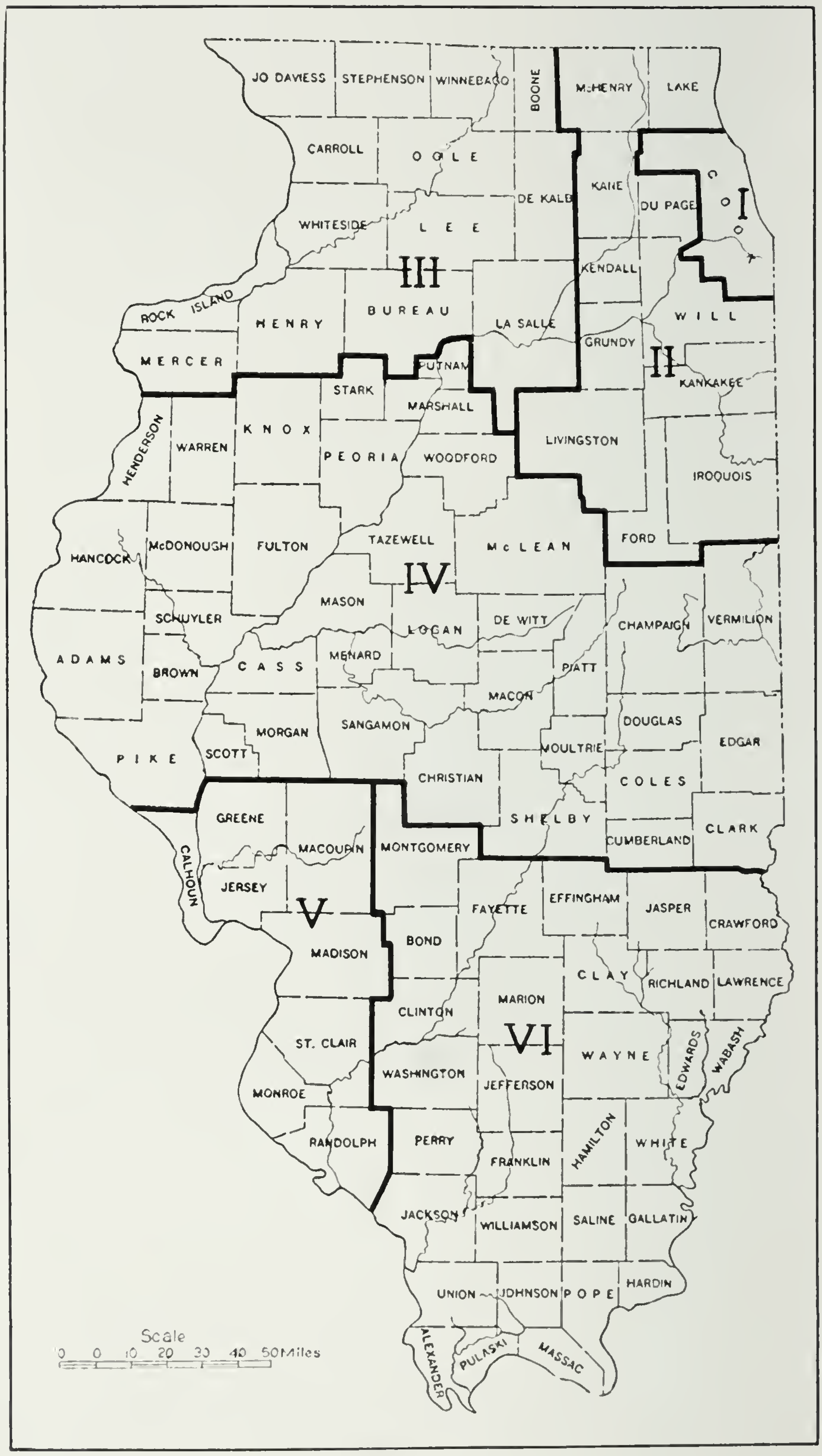

Fig. 8.—Index Map of Illinois Showing Location of Districts According to Which Production of Sand and Gravel and Limestone (Tables 40 and 41) is Given.

TABLE 40.—PRODUCTION OF SAND AND GRAVEL IN ILLINOIS BY DISTRICTS, 1933–1935

District Number (See Fig. 8)	1933[a]		1934[a]		1935 [a] [c]	
	Tons	Value	Tons	Value	Tons	Value
			Structural Sand			
I, II	242,395	$114,680	152,254	$ 61,102	506,158	$194,020
III	123,767	58,830	124,174	62,236	215,725	80,560
IV	162,989	86,923	149,003	86,760	187,012	98,855
V	170,774	57,446	174,142	88,119	129,069	73,657
VI	24,443	7,973	6,529	4,206	28,908	17,867
			Paving and Roadmaking Sand			
I, II	373,432	165,393	468,029	138,252	182,713	71,707
III	114,351	58,522	90,399	45,296	102,235	40,263
IV	311,061	156,236	257,360	125,761	369,122	152,673
V	191,587	60,341	129,084	63,687	138,000	77,100
VI	94,677	46,970	69,833	46,736	36,830	24,768
			Structural Gravel			
I, II	246,330	122,369	267,251	113,741	749,716	318,737
III	124,107	62,809	151,172	91,423	230,936	113,692
IV	187,030	112,679	169,700	100,462	279,312	158,577
V	([b])	([b])	([b])	([b])	([b])	([b])
VI	15,774	10,507	9,986	5,561	42,704	24,063
			Paving and Roadmaking Gravel			
I, II	730,143	336,305	632,601	227,890	283,136	127,332
III	215,251	110,171	228,104	112,166	418,435	181,198
IV	598,578	308,790	350,220	181,942	577,977	256,335
V	([b])	([b])	([b])	([b])	([b])	([b])
VI	104,819	70,333	80,263	58,604	72,446	36,536
			Railroad Ballast Sand and Gravel			
I, II	246,640	102,784	233,500	79,556	783,917	226,004
III	16,660	8,290	([b])	([b])	25,480	10,527
IV	116,540	43,966	40,654	22,237	57,284	27,706
V	....	....	....	....	....	....
VI	([b])	([b])	([b])	([b])	([b])	([b])
			Other Sand and Gravel			
I, II	24,711	8,430	172,107	85,624	11,429	5,374
III	776,302	959,725	942,815	1,177,005	1,137,295	1,607,055
IV	28,762	21,836	20,028	22,699	49,502	32,603
V	([b])	([b])	([b])	([b])	([b])	([b])
VI	37,517	15,949	54,719	30,428	73,640	48,452
			Total Sand and Gravel			
I, II	1,862,651	852,481	1,925,742	706,165	2,517,882	961,194
III	1,370,438	1,258,347	1,554,797	1,501,320	2,130,106	2,033,295
IV	1,404,960	730,430	1,085,820	591,536	1,520,209	726,749
V	379,462	130,998	344,680	170,823	349,820	175,971
VI	299,274	161,189	248,428	157,702	294,888	168,994
Illinois	5,316,784	$3,133,445	5,159,467	$3,127,546	6,812,905	$4,066,203

[a] Commercial producers only.

[c] Preliminary figures. See final totals in Table 1, p. 8. Final figures for separate districts not available.

TABLE 41.—PRODUCTION OF LIMESTONE IN ILLINOIS BY DISTRICTS, 1933–1935

District Number (See Fig. 8)	1933[a]		1934[a]		1935[a][c]	
	Tons	Value	Tons	Value	Tons	Value
			Road Metal and Concrete			
I	702,241	$403,662	1,102,415	$693,510	1,189,779	$661,830
II	410,816	290,973	515,687	370,156	364,088	262,977
III	45,142	36,000	119,533	109,939	146,578	112,702
IV	47,563	51,855	183,668	189,177	88,424	86,176
V	462,142	334,401	641,903	502,272	659,205	567,097
VI	91,582	84,647	104,036	98,349	68,420	51,386
			Railroad Ballast			
I	(b)	(b)	96,467	51,234	125,872	62,835
II	64,753	47,693	119,648	89,633	227,764	167,646
III	...	...	...	...	...	...
IV	...	...	...	...	...	...
V	(b)	(b)	(b)	(b)	(b)	(b)
VI	(b)	(b)	(b)	(b)	...	...
			Agricultural Limestone			
I	36,750	22,350	48,400	30,650	34,055	15,858
II	40,812	22,279	76,600	48,661	55,753	34,591
III	9,903	10,875	10,824	9,173	14,154	11,366
IV	14,621	17,434	59,543	47,208	20,369	24,895
V	104,818	75,651	223,596	131,267	166,084	114,917
VI	14,346	12,533	29,845	24,802	29,665	20,077
			Flux			
I	130,800	71,880	251,800	142,250	332,025	169,802
II	...	...	...	...	...	...
III	...	...	...	...	...	...
IV	(b)	(b)	1,088	1,584	(b)	(b)
V	(b)	(b)	(b)	(b)	5,079	6,429
VI	...	...	...	...	...	...
			Rubble and Rip Rap			
I	19,450	19,200	(b)	(b)	(b)	(b)
II	(b)	(b)	(b)	(b)	15,257	16,554
III	(b)	(b)	(b)	(b)	...	...
IV	(b)	(b)	25,186	15,258	(b)	(b)
V	84,880	89,618	124,507	122,876	75,504	72,804
VI	(b)	(b)	(b)	(b)	(b)	(b)
			Miscellaneous Limestone			
I	(b)	(b)	(b)	(b)	65,365	68,226
II	(b)	(b)	(b)	(b)	25,515	33,119
III	(b)	(b)	(b)	(b)	(b)	(b)
IV	(b)	(b)	8,949	25,321	24,029	49,521
V	9,774	37,544	7,296	26,470	131,891	155,386
VI	...	...	...	...	...	...
			Total Limestone			
I	954,541	557,492	1,618,389	1,029,048	1,864,057	1,101,946
II	523,362	355,328	718,100	518,873	688,377	514,887
III	55,725	49,450	131,627	126,624	164,392	126,522
IV	70,987	94,457	278,434	278,548	135,391	163,580
V	682,767	551,580	1,013,370	796,724	1,073,773	943,724
VI	109,979	100,943	141,640	131,834	101,848	76,722
Illinois	2,397,361	$1,709,250	3,901,560	$2,881,651	4,027,838	$2,927,381

[a] Commercial producers only.
[b] Concealed in total; less than three producers.
[c] Preliminary.

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REPORT OF INVESTIGATIONS—NO. 44

THE MICA IN ARGILLACEOUS SEDIMENTS

By

R. E. GRIM, R. H. BRAY, AND W. F. BRADLEY

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THE MICA IN ARGILLACEOUS SEDIMENTS†

R. E. Grim,* R. H. Bray,** and W. F. Bradley***

Introduction

The determination of the mineral composition[1] of a variety of soils, clays, and shales, mostly from Illinois, has revealed in many of them a constituent belonging to the mica group of minerals and somewhat similar to muscovite, heretofore referred to as the "sericite-like" mineral. Other investigators[2] have noted what is apparently the same mineral in similar sediments, describing it as resembling muscovite, but as differing from it by containing less potash and more water. It has been called "hydromica" or sericite, the latter term being used because some of its physical properties appeared to be similar to those which have been associated with the mineral sericite.

Recently Endell,[3] Hofmann, and their co-workers have described a mineral from argillaceous sediments as "glimmerton," which has the same optical and x-ray properties[4] and mode of occurrence as the "sericite-like" mineral. It is probable that the mineral described by Ross and Kerr[5] as the "potassium-bearing clay mineral" is also similar to the "sericite-like" mineral. Values given by Ross and Kerr for indices of refraction and birefringence are somewhat lower than those of the material herein studied, but the presence of small amounts of impurities, such as quartz and beidellite, would account for these variations and also for the very high silica-to-alumina ratio shown by their formula approximately representing one sample.

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[1] Grim, R. E., Petrology of Pennsylvanian shales and noncalcareous underclays associated with Illinois coals: *Bull. Am. Cer. Soc.*, vol. **14**, pp. 113–119; 129–134; 170–176, 1935.

Bray, R. H., Grim, R. E., and Kerr, P. F., Application of clay mineral technique to Illinois clay and shale: *Bull. Geol. Soc. Am.*, vol. **46**, pp. 1909–1926, 1935.

Grim, R. E., and Bray, R. H., The constitution of various ceramic clays: *Jour. Am. Cer. Soc.*, vol. **19**, pp. 307–315, 1936.

Grim, R. E., Bray, R. H., and Bradley, W. F., The constitution of bond clays and its influence on bonding properties: *Trans. Am. Foundrymen's Assoc.*, vol. **7**, No. 5, pp. 211–228, 1936.

[2] Bayley, W. S., Kaolin in North Carolina with a brief note on hydromica: *Ec. Geol.*, vol. **15**, pp. 236–246, 1920.

Hickling, G., China clay, its origin and nature: *Trans. Inst. Min. Eng.*, vol. **36**, pp. 10–33, 1908–9.

Galpin, S. L., Studies of flint clays and their associates: *Trans. Am. Cer. Soc.*, vol. **14**, pp. 301–346, 1912.

[3] Endell, K., Hofmann, U., Maegdefrau, E., Über die Natur des Tonanteils in Rohstoffen der Deutschen Zement-Industrie: *Zement*, vol. **24**, pp. 625–632, 1935.

Thus, there is no doubt that a mineral belonging to the mica group is a common constituent of argillaceous sediments. So far as is known, no attempts have been made to study this material in detail. Frequently it is found intimately mixed with other clay minerals in a very fine particle size so that analytical data concerning it are difficult or impossible to obtain. By the use of supercentrifuge fractionation technique[6] it has now become possible to obtain the mineral in a relatively pure state in certain fractions of colloidal size, from several shales, clays, and slightly weathered tills. The purest samples have been obtained in the fraction composed of particles varying from about 0.1 micron to about 0.06 micron in diameter,[7] which has been designated as the fine colloid fraction. This paper presents the results of a detailed investigation of this purified material.

NOMENCLATURE OF THE MICA MINERAL IN ARGILLACEOUS SEDIMENTS

The question arises whether the mica mineral in argillaceous sediments should be (1) classed with some species of mica, such as muscovite, phengite, or damourite, (2) denominated as sericite, "sericite-like," "hydromica," or "glimmerton," or (3) designated by a new name.

The data herein presented show that it is not possible to designate the mineral as muscovite, phengite, or any other recognized mica species because (1) it possesses important differences in composition from those assigned to other mica species, (2) it is formed as an authigenic mineral[8] in argillaceous sediments soon after deposition from the original debris and also probably as an alteration weathering product, whereas muscovite and other species of mica have mainly a different mode of origin as igneous or hydrothermal minerals, (3) it occurs in situations different from those in which most muscovite and other mica species occur, and (4) it is found in a physical state that does not convey the usual conception of the properties of muscovite. The mineral occurs commonly in particles less than one micron in diameter, and consequently a mass of it appears unlike a mass of sheets of muscovite. Thus, it would be confusing to designate soil colloidal material by the name muscovite or some other recognized species of mica.

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[4] This similarity was determined following an interchange of material by Hofmann and Grim. X-ray analyses were made on the exchanged material by Hofmann; optical analyses by Grim.

[5] Ross, C. S., and Kerr, P. F., The clay minerals and their identity: *Jour. Sed. Pet.*, vol. **1**, p. 59, 1931.

[6] Bray, R. H., Grim, R. E., and Kerr, P. F., *Idem*, 1935.

[7] Effective diameter as calculated from Stokes' law.

[8] Grim, R. E., *Idem*, 1935.

Similarly, it is not desirable to class the mineral as sericite, "sericite-like," "hydromica," or "glimmerton." The use of the term sericite has been varied. As a mineral name, sericite has been loosely used for material differing from muscovite only in its physical characteristics. Some material designated as sericite has been shown to differ from muscovite by containing less potash and more water,[9] or by variations[10] in other components. Rogers[11] has suggested that the term be restricted to a low temperature hydrothermal mineral. Sericite may indicate, therefore, a white mica with certain attributes, as physical properties, chemical composition or origin, depending upon the user of the term. Unavoidably such diverse usage has led to confusion, so that at the present time a precise concept is not conveyed when a mineral is designated as sericite. It means only a white mica which the user of the term has not wished to class as muscovite for some reason which is usually not stated. If the term sericite were to be used for the mica in argillaceous sediments in any definite sense it would require a specific new definition on the basis of composition and occurrence which would eliminate some material previously included under it. The present confusion regarding the term sericite would be increased by placing the mica herein considered under this term.

The terms "sericite-like," "hydromica," and "glimmerton" (clay mica) are not satisfactory means of designating the material. "Sericite-like" is undesirable because of the vagueness of the significance of sericite, as discussed above. "Hydromica" implies any mica more highly hydrated then muscovite, and although the mica herein considered is more highly hydrated than muscovite, its composition differs from muscovite and all other micas in other important ways, as will be shown. Moreover, other micas differing from it in occurrence or in some phase of composition may be more highly hydrated than muscovite and are, therefore, "hydromicas." The term "glimmerton" implies nothing of composition or relation to other micas, but only a mica occurring in clays. A more specific term is needed—to indicate for example, that the clay mineral mica in argillaceous sediments is distinctive from previously named species.

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[9] Shannon, E. V., The minerals of Idaho, *U. S. Nat. Mus., Bull.* **131**, 1926.

[10] Niggli, P., Zur Zusammensetzung und Bildung der Sericite: *Schweiz. Miner. u. Petrog. Mitt.*, vol. **13**, pp. 84–90, 1933.

[11] Rogers, A. F., Sericite, a low temperature hydrothermal mineral: *Ec. Geol.*, vol. **11**, pp. 118–150, 1910.

There remains only the alternative of giving a new name to the mica occurring in argillaceous sediments, and the term *illite*, taken from the State of Illinois, is here proposed. It is not proposed as a specific mineral name, but as a general term for the clay mineral constituent of argillaceous sediments belonging to the mica group. Many additional analyses must accumulate before the limits of variation of illite are known, and therefore, before it can be specifically named. The writers favor the use of a new name at this time before all limits of variations are known for the following reasons. (1) Because of differences from other mica minerals in composition, occurrence, and origin, a new name or new names for the clay mineral mica in argillaceous sediments will be required. It will cause no confusion to apply now a new general term to this material although future analytical data may make it possible to differentiate what is here included in illite into separate species with specific names, in which case the term illite may be utilized as a group or family name. (2) Petrographic analyses of clays, soils, and shales so urgently require a name to describe this common constituent that it is believed that a new name is fully justified at this time. The additional analyses necessary for specific naming will require a considerable interval of time to accumulate. The least confusion in solving the problem will arise if the required analytical data can be gathered under a definite term.

It is probable that mica similar to that herein described may occur in argillaceous material formed as a weathering product. Although such material may not be found in sediments, the writers favor calling it illite if the material cannot be classed with recognized mica species and if it is similar to illite.

Analytical Data of Illite Purified from Illinois Material

The following analytical data are representative examples of the data obtained from a very large number of samples of purified illite from slightly weathered tills, clays and shales from Illinois which have been studied. X-ray and microscopic study with high magnification (1500×) indicate that samples obtained from the Maquoketa shale from Calhoun County, and from the Pennsylvanian underclay from Vermilion County (Nos. 1 and 2 of Tables 1 and 3) are the purest illite samples investigated. The data from them are, therefore, most significant. Samples 3 and 5 (Tables 1 and 3), containing admixed pigmentary limonitic material, and sample 4 containing a small amount of quartz, are included to represent the character of the information obtained from less pure material.

Some analytical properties of certain clay minerals vary with the exchangeable bases which the minerals may contain. Thus, in giving analytical data it is desirable to state the exchangeable bases contained by the analyzed material. The samples herein analyzed contain ammonia as the exchangeable base.

The very small size of the individual particles in the fine colloid fractions has made it impossible to determine all physical properties. The mineral is gray, light green, or light yellow-brown and is micaceous in habit.

By carefully drying aqueous suspensions containing the mineral, it has been possible to obtain aggregates in which the individual particles all have about the same crystallographic orientation.[12] Optical and *x*-ray measurements have been made on these aggregates which can be studied like large single flakes.

Optical data.

The optical data are incomplete because the aggregates on which the measurements were made provide scant information concerning the crystal form and orientation of the mineral. Aggregates were found permitting the determination that 2V is equal to about 5°. An occasional anomalous uniaxial figure can be found. $Bx_a(=X)$ is nearly $=c$.

The indices of refraction in Table 1 were made using liquids which are mixtures[13] of medium Government oil ($C_{10}\pm H_{22}\pm$; $n=1.466$) and monochlor-naphthalene ($C_{10}H_7Cl$; $n=1.633$). Marshall[14] suggested, and Correns and Mehmel[15] and von Baren[16] have shown, that the indices of some clay minerals vary for different immersion liquids. Sample 1 was mounted in bromobenzene plus iodobenzene ($n=1.609$), iodobenzene ($n=1.616$), and quinoline ($n=1.625$). According to von Baren, these liquids are most active in influencing optical values. In the first two liquids, the indices of refraction remained unchanged, in quinoline they were raised slightly. It can be concluded that the optical properties of illite may be slightly influenced by a few liquids. This is in agreement with the concept that the optical properties of clay minerals with relatively low base exchange capacity (see page~~8~~ 826 for exchange capacity values) are influenced to the smallest degree by immersion liquids.

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[12] Bray, R. H., Grim, R. E., and Kerr, P. F., *Idem*, **1935.**

[13] Glass, Jewell J., Standardization of index liquids: *Am. Mineral.*, vol. **19**, pp. 459–465, 1934.

[14] Marshall, C. E., The orientation of anisotropic particles in an electric field: *Trans. Faraday Soc.*, vol. **26**, pp. 173–189, 1930.

[15] Correns, C. W., Mehmel M., Über den optischen und röntgenographische Nachweis von Kaolinit, Halloysit, und Montmorillonit; *Zeit. Krist.*, vol. **94**, pp. 337–348, 1936.

[16] von Baren, F. A., Über den Einfluss verschiedener Flüssigkeiten auf den Brechungsindex von Tonmineralien: *Zeit. Krist.*, vol. **95**, pp. 464–469, 1936.

Table 1. Optical Properties of Illite as Determined on Aggregates of Purified Material at Room Temperature

Sample No.	1	2	3	4	5
γ	1.598	1.588	1.605	1.588	1.610
$\gamma-\alpha$	.033	.033	.035	.033	.035
sign	(−)	(−)	(−)	(−)	(−)
2V	5°±	5°±	small	small	small

1. Fine colloid fraction. Maquoketa (Ordovician) shale near Gilead, Calhoun Co., Illinois.
2. Fine colloid fraction. Pennsylvanian underclay, near Fithian, Vermilion Co., Illinois.
3. Fine colloid fraction. Slightly weathered till, IVb horizon Clarence soil, Ford Co., Illinois.
4. Fine colloid fraction. Cretaceous shale, near Thebes, Alexander Co., Illinois.
5. Fine colloid fraction. Pennsylvanian shale near Petersburg, Menard Co., Illinois.

It is well known that certain anomalous optical characteristics ("Formdoppelbrechung" and "Eigendoppelbrechung") are obtained from aggregates of uniformly oriented minute rod-shaped or flake-shaped isotropic particles when they are placed in liquids. According to Ambronn and Frey,[17] variable double refraction and uniaxial interference figures are produced when such aggregates are mounted in varied index of refraction liquids, and when the size of individual particles is small in relation to the magnitude of the wave length of light used. Biaxial figures and variable double refraction are obtained under similar conditions with anisotropic particles. As the double refraction characteristics of the illite aggregates were found to be the same when determined in liquids with *n* ranging from 1.50 to 1.70, it can be concluded that the optical values are not influenced by "Formdoppelbrechung" or "Eigendoppelbrechung."

It has been shown[18] that the indices of refraction of certain clay minerals vary with loss of water as the temperature is raised to about 200°C. Figure 1 shows that the indices of refraction of illite increase on heating to low temperatures. The values on which Fig. 1 are based were made by allowing small fragments of the material placed on a glass slide to remain in an oven at a given temperature for several hours. The slide and specimen were then removed and the index was measured immediately by the immersion method. Because of the tendency of the clay minerals to take up water rapidly, and because of the influence of temperature on index liquids, the values have no high degree of accuracy. The errors would tend to reduce the observed values below the true values. Figure 1 shows also that the indices of muscovite ground to -1μ increase less than those of illite when heated to the same temperature. Only aggregates of the -1μ muscovite showing random aggregate orientation were available so that mean values alone could be determined.

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[17] Ambronn, H., Frey, A., Das Polarisationsmikroskop. *Leipzig*, 1926.

[18] Correns, C. W., Mehmel, M., *Idem.*, 1936.

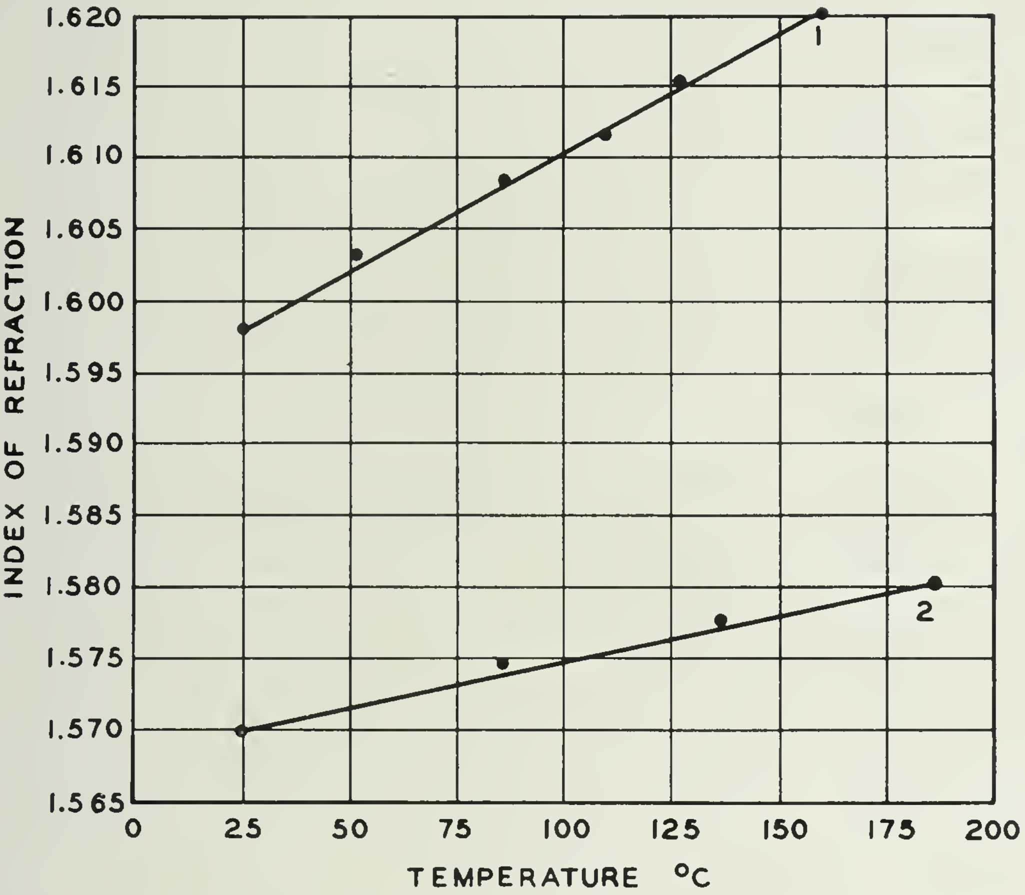

FIG. 1. Relation of index of refraction of illite and muscovite to temperature changes.
No. 1 = γ values for illite, sample 1 of Table 1.
No. 2 = mean values for -1μ muscovite.

Data for samples 1 and 2 (Table 1) obtained under the same conditions indicate that the optical properties of illite may show slight variations. Such variations are to be expected in view of the fact that the chemical composition may vary slightly (Table 3). Correns and Mehmel[19] have published results suggesting that for montmorillonite the indices of refraction increase with the Mg content. For illite sample 1 has a higher MgO content and higher indices of refraction than has sample 2. Data are not at hand to evaluate the influence of all components of clay minerals on their optical properties, so that it must not be concluded that a variation in the MgO content of illite is the only variation in composition which influences optical properties.

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[19] Correns, C. W., Mehmel, M., *Idem*, 1936.

The optical properties of illite are similar to those of muscovite except for a smaller value for 2V, and a greater variation of indices of refraction on heating to low temperatures. According to Dana,[20] 2V diminishes in micas, relatively, as the silica increases, from which it would be anticipated (see chemical composition) that 2V for illite would be smaller than for muscovite.

*X-ray data.**

Diffraction data for muscovite, illite (Sample 1 of Table 1), and sericite[21] from the Longfellow mine in California are given in Table 2. Columns one and two give the indices and calculated values of d_{hkl} for muscovite using the data of Jackson and West.[22] Column three gives values of F for one molecule calculated from data of Jackson and West and from the present data. Columns four to six give observed values of d and estimated relative intensities for the indicated samples. The breadth of the diffraction lines increases in the order: muscovite, Longfellow sericite, illite; but no significant variation in d is found. Powder diffraction diagrams of the illite show only a faint haze between $d = 4.47$Å and $d = 3.31$Å, but diffraction from a uniformly oriented flake-shaped aggregate of particles shows perceptible reflections in the $11l$ and $02l$ row lines as indicated; $13l$ and $20l$ are also more easily recognized in the flake diffractions.

The unit cell of illite seems to be shorter by about one-third of one per cent than the unit cell of muscovite, possibly because of its somewhat lower K_2O content (see chemical data). Except for this slight difference, the only crystallographic variation between the muscovite, Longfellow sericite, and illite is in particle size, or equivalently, in the perfection of crystallization.

It has been shown[23] that the chemical composition of structures of this type can vary appreciably without pronounced changes in the dif-

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[20] Dana, E. S., *Textbook of Mineralogy*, Edited by W. E. Ford. J. Wiley and Sons, New York, **1921.**

* Diffraction patterns were obtained in the laboratory of the University of Illinois through the cooperation of Professor G. L. Clark.

[21] Samples of the sericite were obtained from Prof. P. F. Kerr, Columbia University, New York, N. Y.

[22] Jackson, W. W., and West, J., The crystal structure of muscovite: *Zeit. Krist.*, vol. **76,** pp. 211–227, 1930.

[23] Marshall, C. E., Layer lattices and the base-exchange clays: *Zeit. Krist.*, vol. **91,** pp. 433–449, 1935.

TABLE 2

Muscovite calculated from Jackson and West with some additions			Muscovite observed (powder)		Sericite Longfellow mine, observed (powder)		Illite (Sample 1 of Table 1) observed (flake and powder)	
Indices	Calc. d_{hkl}	*F* for 1 molecule. Calc. for MoKα	*d*	*I*	*d*	*I*	*d*	*I*
002	9.96	15.5	9.99	s	9.96	ss	9.98	s
004	4.98	25.6	4.98	m	4.97	s	4.97	w
020	4.51	4						
110	4.48	19	4.47	ss	4.47	ss	4.47	s
$11\bar{1}$	4.45	20						
021	4.40	11						
111	4.295	9	4.29	w	4.3	ww		
$11\bar{2}$	4.215	4						
022	4.11	8	4.11	w	4.11	w	4.11	ww
112	3.965	9	3.95 db	ww	3.95 db	ww		
$11\bar{3}$	3.865	19	3.87	m	3.87	m		
023	3.73	21	3.72	m	3.75	s	3.7	ww
113	3.58	6	3.55	ww				
$11\bar{4}$	3.48	38	3.475	m	3.44	s	3.4	ww
024	3.34	24						
006	3.32	40	3.32	ss	3.32	ss	3.31	m
114	3.20	38	3.20	m-s	3.22	s	3.2	ww
$11\bar{5}$	3.11	12	3.1	ww				
025	2.987	35	2.98	s	2.99	s	2.98	w
115	2.862	29	2.86	m	2.85	m	2.84	ww
$11\bar{6}$	2.785	33	2.78	m	2.77	m		
$13\bar{1}$	2.592	35						
200	2.580	37	2.585	w	2.58	w		
116	2.570	29						
131	2.560	43						
$20\bar{2}$	2.555	46	2.560	ss	2.56	ss	2.56	s
$13\bar{2}$	2.545	38						
008	2.49	18	2.49	w	2.50	ww		
132	2.485	56						
$13\bar{3}$	2.458	25	2.46	w	2.45	w	2.44	w
202	2.441	14		ww				
$20\bar{4}$	2.387	46	2.390 db	m				
133	2.380	51	2.376		2.38	m	2.38	m
134	2.26	51						
040	2.255	18						
$22\bar{1}$	2.245	20	2.245 bd	w	2.235	w	2.24	m
041	2.24	18						
220	2.238	4						
$13\bar{5}$	2.228	10						
221	2.205	21						
$22\bar{3}$	2.179	34	2.185	w	2.185	w	2.18	w
222	2.142	19						

TABLE 2. (*Continued*)

Muscovite calculated from Jackson and West with some additions			Muscovite observed (powder)		Sericite Longfellow mine, observed (powder)		Illite (Sample 1 of Table 1) observed (flake and powder)	
Indices	Calc. d_{hkl}	*F* for 1 molecule. Calc. for MoKα	*d*	*I*	*d*	*I*	*d*	*I*
$20\bar{6}$	2.142	33	2.14	db m				
043	2.136	16	2.13		2.13	m	2.11	w
135	2.13	36						
$13\bar{6}$	2.098	29						
223	2.07	14	2.05	ww	2.05	ww		
044	2.054	14						
136	2.002	7						
0010	1.991	57	1.991	s	1.991	m	1.98	m
206	1.948	24	1.95	w	1.95	w		
$04\bar{6}$	1.865	23	1.83	ww				
138	1.756	31	1.76	w				
208	1.715	18						
0012	1.660	9						
$13\overline{10}$	1.660	2	1.654	w	1.66	w	1.65	w
$20\overline{10}$	1.657	56						
312	1.640	18	1.64	m	1.64	m	1.64	m
313	1.602	20	1.60	w	1.60	ww		
314	1.555	18	1.55	w	1.55			
1310	1.514	50	1.52	w	1.52			
2010	1.509	41						
060	1.503	65	1.504	s	1.50	s	1.50	s
$33\bar{1}$	1.498	65						
062	1.486	16						
$33\bar{3}$	1.483	15						
331	1.480	21						
0014	1.423	24						
$33\bar{7}$	1.371	6						
335	1.345	6	1.344	m	1.344	w	1.34	ww
			1.335	w	1.335	w		
260	1.30	39						
$40\bar{2}$	1.296	45						
400	1.290	51	1.295	bd w	1.295	w	1.29	m
068	1.288	26						
$33\bar{9}$	1.289	28						
337	1.287	30						
402	1.263	31						
$40\bar{6}$	1.245	26						
0016	1.245	30	1.245	bd w	1.245	w	1.24	w
264	1.242	32						

Observed diffractions were obtained with CuKα radiation.

Key: ss = very strong, s = strong, m = medium, w = weak, ww = very weak, db = discernible doublet, bd = broad.

fraction pattern. Although illite differs somewhat in chemical composition from muscovite, it is not surprising, therefore, that it should possess about the same structure.

The illite sample (Sample 1 of Table 1) does not contain diffraction lines of quartz.

Chemical data.

Computed on the basis of the analyses of the purest samples (Nos. 1 and 2 of Table 3), the composition of illite may be approximately expressed as $2K_2O \cdot 3MO \cdot 8R_2O_3 \cdot 24SiO_2 \cdot 12H_2O$. Considerable analytical work shows that the composition of the mineral is subject to some slight variation. Additional analyses of purified material must be gathered before the exact limits of the variations are known.

TABLE 3. CHEMICAL ANALYSES OF ILLITE*

	1	2	3	4	5
SiO_2	50.10	51.22	47.21	52.23	44.01
Al_2O_3	25.12	25.91	21.47	25.85	26.81
Fe_2O_3	5.12	4.59	10.73	4.04	11.99
FeO	1.52	1.70			
MgO	3.93	2.84	3.62	2.69	2.43
CaO	0.35	0.16	0.21	0.60	0.11
Na_2O	0.05	0.17		0.33	0.07
K_2O	6.93	6.09	5.78	6.56	4.78
TiO_2	0.50	0.53		0.37	0.64
Ign. Loss†	6.82	7.49	10.99	7.88	9.19
Total	100.44	100.70	100.01	100.55	100.03
H_2O+	7.18	7.14	6.17	7.88	8.08
H_2O-	1.90	1.45	3.80	1.13	2.33
SiO_2/R_2O_3	3.00	3.02	2.84	3.13	2.17
SiO_2/Al_2O_3	3.39	3.36	3.51	3.43	2.79

1. Fine colloid fraction, Ordovician (Maquoketa) shale, near Gilead, Calhoun County, Ill.
2. Fine colloid fraction, Pennsylvanian underclay, near Fithian, Vermilion County, Ill.
3. Fine colloid fraction, slightly weathered till, IVb horizon of Clarence soil, Ford County, Ill.
4. Fine colloid fraction, Cretaceous shale, near Thebes, Alexander County, Ill.
5. Fine colloid fraction, Pennsylvanian shale, near Petersburg, Menard County, Ill.

* Analyses 1, 2, 4 and 5 were made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey; analysis 3 was made under the supervision of R. H. Bray.

† The loss on ignition values for samples 1, 2, 4 and 5 are based on material dried to 110°C.; for sample 3 it is based on air dried material.

It is noteworthy that illite has a SiO_2 to R_2O_3 ratio of about 3. This ratio higher than 2, which is generally characteristic of most mica, is not the result of admixed quartz or other minerals, such as pyrophyllite, with high SiO_2 to Al_2O_3 ratios, as the *x*-ray and optical analyses of samples 1 and 2 show that these samples consist of a single mineral. The MgO and FeO (MO) content are of sufficient magnitude and uniformity to require a place in the formula. The K_2O and H_2O contents, which are relatively low and high, respectively, for micas, are also noteworthy.

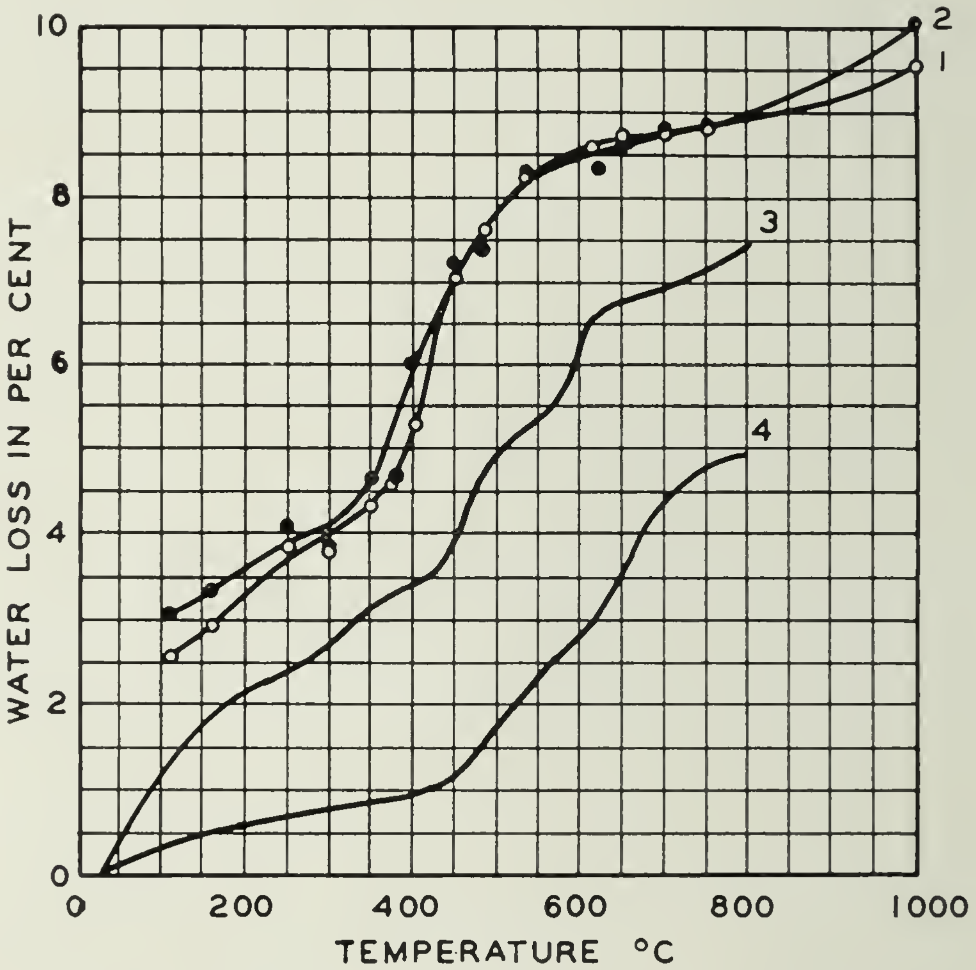

FIG. 2. Dehydration curves of illite and muscovite.
No. 1—Sample 1 of Table 1.
No. 2—Sample 2 of Table 1.
No. 3—Very finely ground muscovite.
No. 4— −100 mesh muscovite (coarser than 3).
Curves 3 and 4 after Kelley, Jenny and Brown; *Soil Sci.*, 1936.

Samples 3, 4 and 5 are less pure than 1 and 2. Samples 3 and 5 contain admixed limonitic material, and sample 4 contains quartz. The presence of these constituents must be recognized in considering the significance of the analyses of the samples.

Dehydration data.

Dehydration curves (Fig. 2) obtained from illite resemble more closely the curve for very finely ground muscovite than that of −100 mesh muscovite or those of other clay minerals.[24] Dehydration data for other micas are not available for comparative study.

Kelley, Jenny, and Brown[25] have recently shown that very fine grinding of various hydrous minerals tends to shift the inflection point to a lower temperature and to apparently reduce the crystal lattice water with the difference appearing as adsorbed water. This effect is shown by their curves for −100 mesh muscovite and for the same mineral very finely ground (Fig. 2). They have concluded that "differences in the inflection points do not necessarily signify different lattices but may be the result merely of variations in particle size." It follows that dehydration curves should not be used as diagnostic characteristics of minerals unless particle size is considered. Until dehydration data can be obtained for illite of varying particle size, the dehydration characteristics of the mineral and their value in identifying it cannot be determined fully.

TABLE 4. WATER LOSS DETERMINATIONS OF ILLITE*

Temperature °C.	Water loss in per cent	
	Sample 1	Sample 2
110	2.60	3.03
160	2.92	3.41
250	3.82	4.12
300	3.63	3.84
350	4.45	4.62
375	4.62	4.62
400	5.37	6.01
450	7.03	7.24
485	7.56	7.47
530	8.37	8.31
615	8.54	8.41
650	8.74	8.62
700	8.74	8.79
750	8.77	8.79
1000	9.60	10.14

* Determinations made under the supervision of O. W. Rees, Associate Chemist, Illinois State Geological Survey. Location of samples given in Tables 1 and 3.

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[24] For dehydration curves of other clay minerals see Ross, C. S., and Kerr, P. F., P.P. **165E**, *U.S.G.S.*, 1930; Endell, K., Hofmann, U., and Maegdefrau, E., *Zement*, vol. **24**, 1935; Kelley, W. P., Jenny, H., and Brown, S. M., *Soil Sci.*, vol. **41**, 1936.

[25] Kelley, W. P., Jenny, H., and Brown, S. M., Hydration of minerals and soil colloids in relation to crystal structure: *Soil Sci.*, vol. **41**, pp. 259–274, 1936.

Base-exchange data.

Base-exchange capacity values (Table 5) obtained on samples of illite range from about 20 to 40 milliequivalents per 100 grams. These values are lower than the value (about 50 milliequivalents per 100 grams) assigned by Hofmann, Endell[26] and their coworkers to "glimmerton" which is similar to illite. Base-exchange capacity varies with particle size so that this property should be expressed as ranging between limits. Magnitude rather than specific values are important because of variations in particle size, and also because of variations due to slight differences in composition.

TABLE 5. BASE-EXCHANGE CAPACITY

Sample No. (location Table 1)	1	2	3	4	5
Inorganic base exchange capacity in milliequivalents/100 grams	20.5	35.5	33.0	30.0	21.6

In previous reports[27] the question has been raised as to whether illite (the "sericite-like" mineral) has low base-exchange capacity or no base-exchange capacity. If no base-exchange capacity is assigned to illite in the samples studied, the base-exchange capacity shown by the samples (Table 5) can only be explained by the presence in each sample of a second mineral with high exchange capacity. Assuming for an admixed mineral a base-exchange capacity even of 100 (a high value for montmorillonite which possesses the highest exchange capacity of the clay minerals), the quantity necessary to yield the capacities would be appreciable. As already noted, x-ray and optical data reveal no constituent in the samples other than illite, except quartz and limonite in Nos. 3, 4, and 5, and these minerals would tend to decrease rather than increase base-exchange capacity values. Theoretical reasons[28] have been presented showing that the micas should possess base-exchange capacity. In the present research, exchange capacity values of the same order of magnitude shown for illite have been obtained from pure crystalline muscovite after grinding it to a diameter of about 1 micron, the ground material retaining the x-ray diffraction pattern characteristic of muscovite.

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[26] Endell, K., Hofmann, U., and Maegdefrau, E., Über die Natur des Tonanteils in Rohstoffen der Deutschen Zement-Industrie: *Zement*, vol. **24**, pp. 625–632, 1935.

[27] Grim, R. E., and Bray, R. H., *Op. cit.*, **1936**.

Grim, R. E., Bray, R. H., and Bradley, W. F., *Op. cit.*, **1936**.

[28] Van der Meulen, J. B., Relation between the phenomena of cation exchange with silica-alumina complexes and their crystal structure: *Rec. trav. chim.*, vol. **54**, pp. 107–113, 1935.

Relation of Illite to Other Micas

The analytical data provide conclusive evidence that illite is a member of the mica group of minerals and somewhat similar to muscovite. Its optical values agree with those for muscovite, except for a smaller value for 2V, and a greater variation of indices of refraction on heating to low temperatures. Illite and muscovite yield diffraction patterns with lines having the same spacings. The former mineral may be distinguished, however, by the greater width of the lines. The mineral can be differentiated from muscovite on the basis of its chemical composition because of a higher SiO_2 to R_2O_3 ratio, a higher SiO_2 to K_2O ratio, a higher R_2O_3 to K_2O ratio, an appreciable content of MO (mainly magnesia), and a higher H_2O content.

On the basis of composition, illite is more nearly similar to the phengite variety of mica than to muscovite. The term phengite has been used for white micas whose analyses suggest a higher SiO_2 to R_2O_3 ratio than 2. Also the presence of MgO in phengite has been noted. Formulae assigned to phengite ($K_2O\cdot(Mg, Fe)O\cdot 2Al_2O_3\cdot 7SiO_2\cdot 2H_2O$ by Winchell;[29] $K_2O\cdot 2Al_2O_3\cdot 6SiO_2\cdot 2H_2O$ by Tschermak;[30] $K_2O\cdot RO\cdot 2Al_2O_3\cdot 6SiO_2\cdot 2H_2O$ by Hallimond)[31] do not agree, particularly in their SiO_2 to K_2O ratios, with the analyses of illite (Table 3). A search of the literature revealed analyses 1 and 2 (Table 4) of phengite most nearly like the compositions given in Table 3. It is evident that even these specially selected analyses are not closely similar to those of illite, and, therefore, there is no justification, on the basis of composition, for designating the mineral studied as phengite.

The deep red mica from the manganese mines of St. Marcel in Italy named alurgite by Breithaupt and analyzed by Pennfield,[32] and mariposite from the Josephine mine, Bear Valley, California, analyzed by Hillebrand,[33] which Schaller[34] has shown to be the same mineral, is similar in some respects to illite. The analyses (Table 6) show important differences, however, in the H_2O and K_2O values. There is also an essential difference in the mode of occurrence.

Schwartz and Leonard[35] described a micaceous alteration product of

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[29] Winchell, A. N., *Idem*, **1929.**

[30] Tschermak, G., Die Glimmergruppe, *Zeit. Krist.*, vol. **3,** pp. 122–167, 1879.

[31] Hallimond, A. F., On the chemical classification of the mica group: *Mineral Mag.*, vol. **20,** pp. 305–318, 1925.

[32] Pennfield, S. L., On some minerals from the manganese mines of St. Marcel in Piedmont, Italy: *Am. Jour. Sci.*, 3rd Ser., vol. **46,** p. 288, 1893.

[33] Hillebrand, W. F., Mineralogic Notes: *Bull.* **167,** *U.S.G.S.*, p 74, 1900.

[34] Schaller, W. T., Mineralogic Notes, Series 3; *Bull.* **610,** *U.S.G.S.*, pp. 139–140, 1916.

[35] Schwartz, G. M., and Leonard, R. J., Alteration of spodumene in Etta Mine, Black Hills, South Dakota: *Am. Jour. Sci.*, 5th Ser., vol. **11,** pp. 257–264, 1926.

Table 6. Chemical Analyses of Micas Resembling Illite

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	52.28	58.90	46.54	45.72	46.58	40.79	53.22	56.79	47.29	53.47	48.96	47.05
Al_2O_3	23.56	25.28	30.39	37.17	37.46	29.98	21.19	25.11	31.31	32.36	30.96	34.90
Fe_2O_3		2.30	4.42	2.18	0.80	8.07	1.22	0.63	1.19	0.79		1.50
FeO	5.76		2.98			2.48		0.92	0.37	0.42	0.24	
MgO	2.43	1.49	0.94	2.00	1.16	2.71	6.02	3.29	2.38		1.97	1.95
CaO	0.65	0.65	0.35	0.05	tr	0.45	—	0.07	0.69	0.17	0.26	
Na_2O		1.37	1.44	1.44	0.64	0.38	0.34	0.17	0.88	0.44	1.65	7.96
K_2O	9.52	5.73	5.57	6.69	6.38	3.47	11.20	8.92	4.07	7.68	8.47	
TiO_2						1.28	—	0.18				
CrO_3							0.87	—				
MnO							0.18			0.12		
F			0.58								1.04	1.45
Ign. loss	5.94	4.14	5.31	6.79			5.75	4.72		4.07	3.83	4.07
Total	100.44	99.86	98.52	102.04			99.99	100.80			99.38	98.88
H_2O+					6.06	9.34			9.92			
H_2O-					0.30	1.20			1.88			
SiO_2/R_2O_3		3.75	2.38	2.02	2.09	1.97	4.10	3.78	2.50	2.76		
SiO_2/Al_2O_3	3.77	3.96	2.61	2.09	2.12	2.31	4.24	3.84	2.57	2.81		

1. Phengite from Wildschaptachtal. *Doelter's Handbuch der Mineralchemie*, **2,** Abt. 2, p. 428, 1914.
2. Phengite from Witticbes Tal. *Doelter's Handbuch der Mineralchemie*, **2,** Abt. 2, p. 428. 1914.
3. Secondary muscovite, from Epprechstein, *Doelter's Handbuch der Mineralchemie*, **2,** Abt. 2, p. 426, 1914.
4. Damourit, from Fen. Norway. *Doelter's Handbuch der Mineralchemie*, **2,** Abt. 2, p. 422, 1914.
5. Sericite, Carroll-Driscoll mine, Idaho, from E. V. Shannon, *Bull.* **131,** *U. S. Nat. Mus.*, p. 367, 1926.
6. Hydromica, North Carolina, from W. S. Bayley, *Ec. Geol.*, vol. **15,** pp. 236–246, 1920.
7. Alurgite, Manganese mines of St. Marcel, in Piedmont, Italy, from S. L. Pennfield, *Am. Jour. Sci.*, vol. **46,** pp. 288–295, 1890.
8. White mariposite, Josephine mine, Bear Valley, California, from W. L. Hillebrand, *Bull.* **167,** *U.S.G.S.*, p. 74, 1900.
9. Secondary mica, Etta mine, S. Dakota, from G. M. Schwartz and R. J. Seward, *Am. Jour. Sci.*, vol. **11,** p. 262, 1926.
10. Secondary mica, Branchville, Conn., from G. J. Brush and E. S. Dana, *Am. Jour. Sci.*, vol. **20,** p. 274, 1886.
11. Gilbertite, from Ehrenfriedersdorf, *Dana's System of Mineralogy*, p. 618, **1914.**
12. Margarodite, from Zillerthal, *Dana's System of Mineralogy*, p. 618, **1914.**

spodumene from Etta mine, South Dakota, which has values for K_2O, MgO, and H_2O approaching those of illite. It has, however, the SiO_2 to Al_2O_3 ratio of muscovite and is believed to be of hydrothermal origin. Earlier Brush and Dana[36] described an alteration product of spodumene from Branchville, Connecticut, which probably had the same origin as the material from Etta. Except for a slightly higher silica value (Table 6), which was interpreted as indicative of a small amount of free silica, the analysis corresponds to the formula for muscovite.

The names damourite, gilbertite, and margarodite have been given to secondary micas of the muscovite type. Available chemical analyses of these minerals (Table 6) are notably different from those of illite (Table 3). Also, damourite, bilgertite, and margarodite appear mainly to have resulted from hydrothermal alteration.

The mineral described as sericite by Shannon[37] from gouge from the Carroll-Driscoll mine in Idaho (No. 5, Table 6), possesses optical and *x*-ray characteristics similar to those of illite. Chemically, however, there are important differences, particularly in the SiO_2 to Al_2O_3 ratio.

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[36] Brush, G. J., and Dana, E. S., Spodumene and the results of its alteration: *Am. Jour. Sci.*, 3rd Ser. vol. **20,** pp. 257–285, 1880.

[37] Shannon, E. V., The Minerals of Idaho: *U. S. Nat. Museum, Bull.* **131,** 1926. A sample of Shannon's original material was kindly furnished us for *x*-ray analysis. For this courtesy we are indebted to the U. S. Nat. Museum and Dr. W. F. Foshag, Curator of Mineralogy.

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Topographic Mapping in cooperation with the United States Geological Survey

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STRATIGRAPHIC STUDIES OF PENNSYLVANIAN OUTCROPS IN PART OF SOUTHEASTERN ILLINOIS

WILLIAM A. NEWTON AND J. MARVIN WELLER

INTRODUCTION

Location and extent.—The area included in this report comprises seven counties in the southeastern part of Illinois, namely: Coles, Cumberland, Jasper, Richland, Lawrence, Crawford, and Clark counties, the eastern border of the latter three counties being the Wabash River (see index map, fig. 1). The area is bounded on the east and west approximately by the meridians 88° 30′ and 87° 32′ W. respectively, and on the north and south respectively by the parallels 39° 40′ and 38° 38′ N. It is about 75 miles long and 50 miles wide, the total area of these seven counties comprising about 3,047 square miles.

The eastern part of this area includes the Southeastern Illinois oil field which has produced 97 per cent of the State's total oil production to date. The western part includes part of the Illinois basin.

Purpose of the report.—The recent discoveries of new oil fields in the central part of the Illinois basin have led to new interest in the geology of the area. At present there is no published information adequately describing and correlating the rock formations of Pennsylvanian age that are exposed at the surface in the seven counties mentioned above. The purpose of this report is to describe and correlate those formations that crop out at the surface, thus providing a basis for structural studies which may assist in the exploration for oil and gas. It does not include a discussion of geologic history nor of structure, detailed studies of which have not as yet been made in this area.

Acknowledgements.—The field studies for this report were made principally in 1934, 1935, and 1936 by Dr. J. Marvin Weller and Mr. W. A. Newton, and are a part of a larger project covering the Pennsylvanian Stratigraphy of Illinois. Most of the material here included was prepared by Mr. W. A. Newton as a master's thesis at the University of Illinois. Professor Harold R. Wanless, of the Department of Geology and Geography, University of Illinois, was adviser in the preparation of the thesis.

Geologic field notes used in preparing this report include, in addition to those of the authors, some by Mr. Rex McGehee and Mr. Melville W. Fuller, formerly of the State Geological Survey staff.

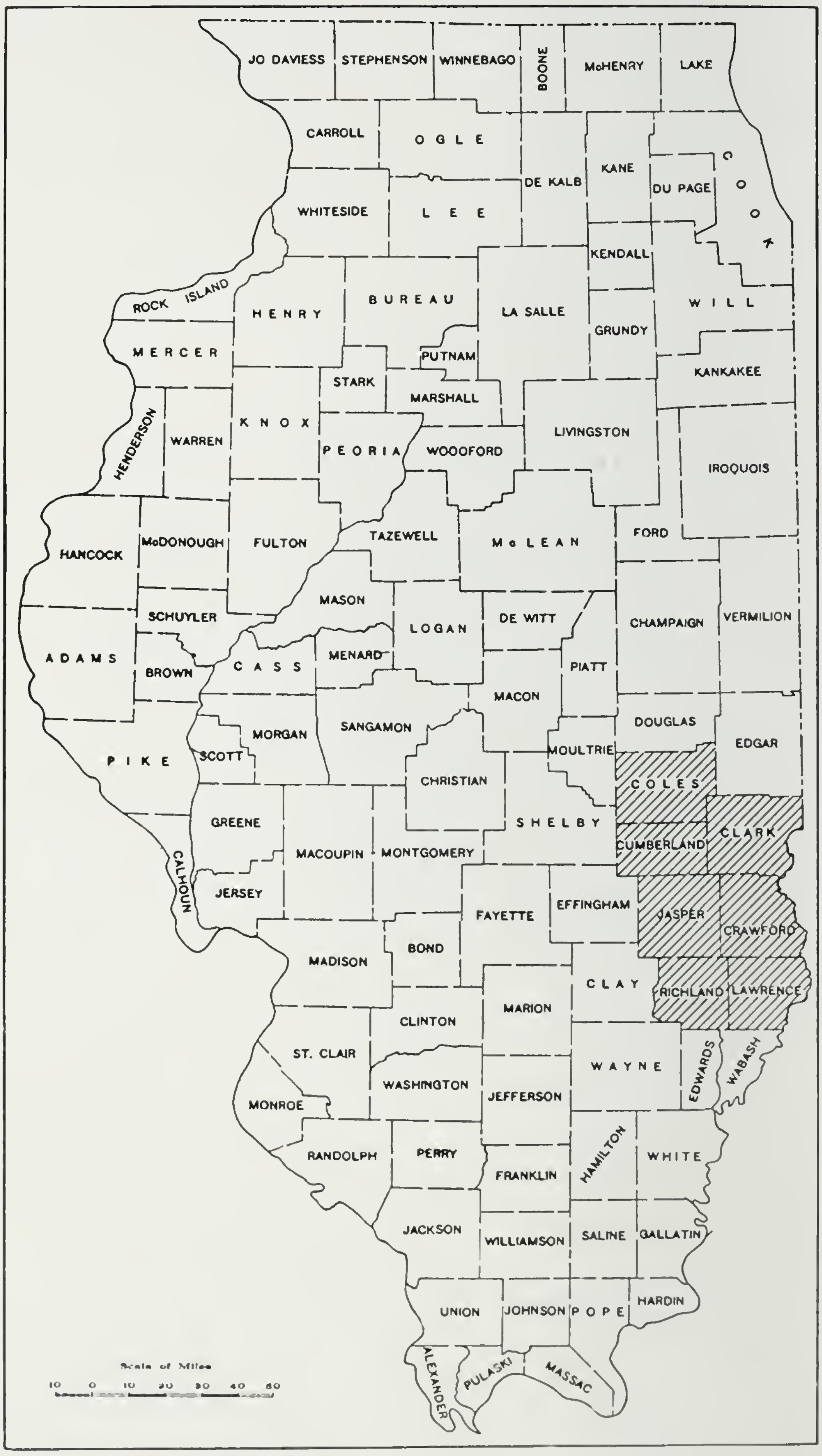

Fig. 1.—Index Map showing area covered in this report.

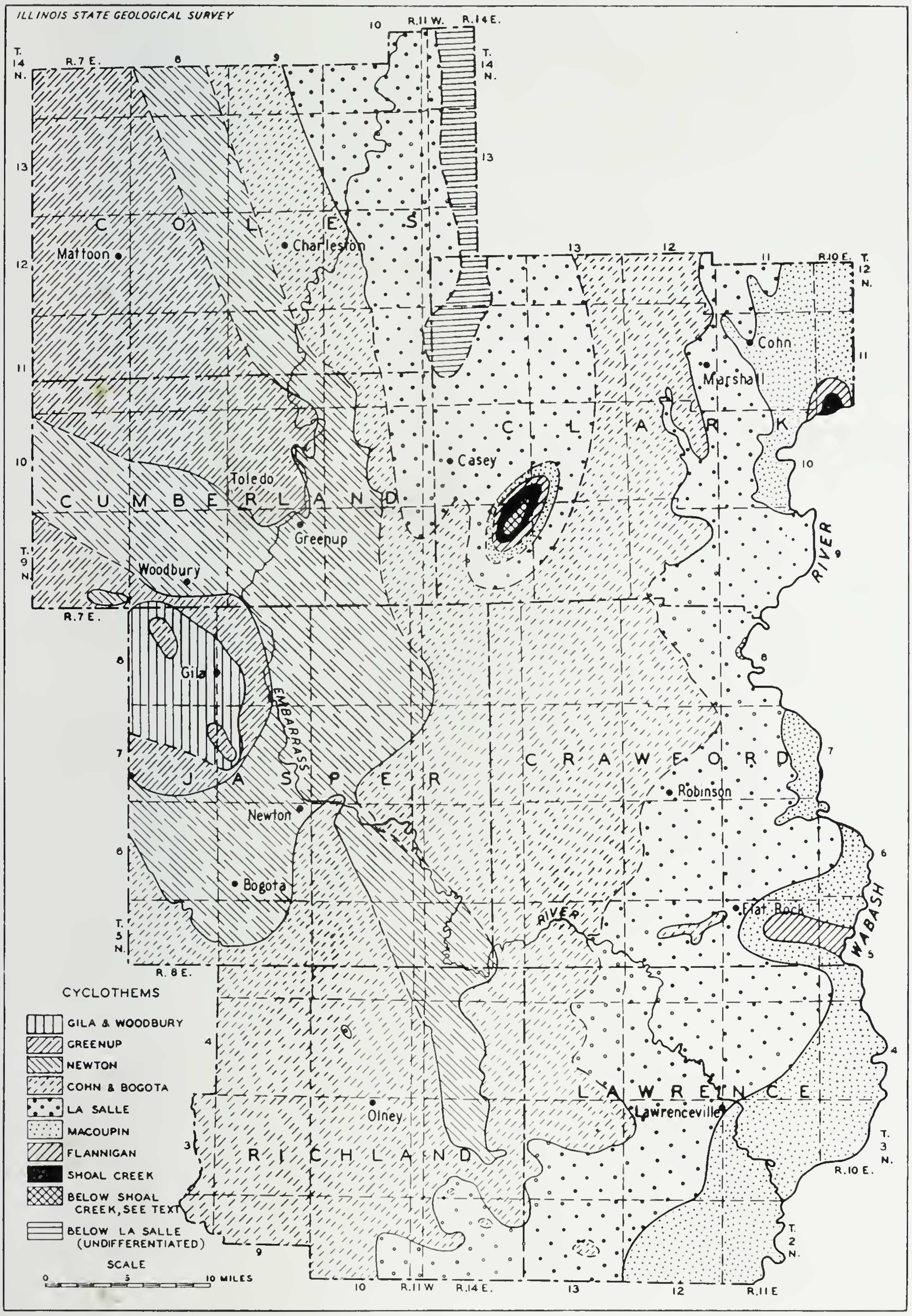

Fig. 2.—Map showing areal geology of part of southeastern Illinois, by cyclothems.

GENERAL GEOLOGY

Discussion.—The area included in this report is largely covered by glacial deposits of Wisconsin, Illinoian, and pre-Illinoian age. Detailed glacial geology is not included in this report. For such information the reader is referred to the citation given below.[1] The surface rocks exposed are all of upper Pennsylvanian age and crop out mainly along the walls of small valleys and gullies and in road cuts.

The youngest rock stratum, which blankets a large part of this area, is tentatively correlated with the Merom sandstone. It may not be of the same geologic age at all localities. In many places it lies disconformably on older strata, and locally the base of this sandstone fills old stream channels (fig. 12, p. 29).

The areal geology map (fig. 2) is based primarily on the outcrops. Because considerable parts of the area are without outcrops the position of the cyclothem boundaries is tentative.

The Survey's files provided subsurface data on the top of the Lower Mississippian which were used particularly for the vicinity of the Clark County oil fields.

In the area shown as undifferentiated Pennsylvanian there are no outcrops. The logs of wells show only about 200 feet of Pennsylvanian strata, most of which is sandstone, and no definite cyclothems can be recognized.

The distribution of cyclothems as shown in this map depends on two factors, structure and topography. Some occurrences of older beds surrounded by younger beds represent an anticline or dome; others are due to the partial removal of a younger formation which has an irregular basal contact.

Plate 1 shows geologic sections of various exposures throughout these seven counties, excluding the Merom sandstone. The numbers at the top of each column refer to the locations shown on the accompanying map. The geologic sections are arranged according to correlations of persistent strata in the cyclothems, such as coal, limestone, or black slaty shale, with no reference to elevation. The great variations in lithology and thickness of the same strata in different outcrops may be noted. The changes in dip of the strata are numerous in this area making correlations difficult. Pennsylvanian correlations in this area have been possible only through detailed geologic field studies and a cognizance of the peculiarities of Pennsylvanian deposition.

Cyclothems exposed in this area.—A group of successive strata, usually exemplifying conditions of both non-marine and marine deposition, is included under the term "cyclothem". The name given to each cyclothem is derived from the locality in which the particular group of beds is known to be best exposed.

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[1] MacClintock, Paul, Physiographic divisions of the area covered by the Illinoian driftsheet in Southern Illinois; Recent discoveries of Pre-Illinoian drift in southern Illinois: Illinois State Geol. Survey Rept. Inv. No. 19, 1929.

A complete cyclothem may have the following members, in order from bottom to top: sandstone, sandy and micaceous shale, "fresh-water" limestone,[2] underclay, coal, "middle" marine limestone, black sheety to slaty shale, calcareous shale ,"upper" marine limestone, and non-silty shale, the latter commonly containing ferruginous concretions. The portion of the cyclothem from the sandstone to the coal is regarded as of continental origin, and that portion from the "middle" marine limestone to the non-silty shale is thought to be of marine origin. This sequence represents the ideal cyclothem, but actually one or more of the members is generally absent. However, the complexities of the stratigraphic section may be understood better by grouping the strata into cyclothems.

The following cyclothems have been recognized in these seven counties, listed with the youngest at the top:

Woodbury.—The type locality is near the town of Woodbury, Cumberland County
Gila.—This is a rudimentary cyclothem locally developed near the town of Gila, Jasper County
Greenup.*—The type locality is just north of the town of Greenup, Cumberland County
Newton.—The type locality is near the town of Newton, Jasper County
Bogota.—The type locality is a few miles southwest of the town of Bogota, Jasper County
Cohn.—The type locality is about 2 miles northwest of Cohn, Clark County
LaSalle.—This cyclothem is known as "upper" and "lower" where two massive limestones are present in the positions of "upper" limestones
The type locality is near the town of LaSalle, LaSalle County
Macoupin.—Named from exposures along Macoupin Creek, south-east of Carlinville, Macoupin County
Flannigan.—Named from exposures in Flannigan Township, Hamilton County
Shoal Creek.—Named from exposures along Shoal Creek, Clinton County
Collinsville.—Named from exposures along Canteen Creek, near Collinsville, Madison County
Trivoli.—Named from exposures in Trivoli Township, Peoria County
Gimlet.—Named from exposures along Gimlet Creek, near Sparland, Marshall County

The cyclothems below the Macoupin are below drainage in practically all parts of the area except in the vicinity of the Martinsville dome. In the SE. ¼ of the NE. ¼ of Clark County there are a few exposures of members belonging to the Flannigan and Shoal Creek cyclothems. Members of the Flannigan cyclothem also outcrop in the extreme southeastern part of Crawford County. The exposures of those cyclothems older than the Macoupin and outcropping near the Martinsville dome are discussed first.

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[2] The characteristics of a "fresh-water" limestone are discussed on page 13 under the description of the LaSalle cyclothem.

* Work done since this report was prepared indicates that the Greenup limestone correlates with the Omega limestone as described in Report of Investigations No. 40. This will be more fully discussed in another publication.

DESCRIPTIVE GEOLOGY

Exposures in the vicinity of the Martinsville dome, Clark County.—Two ravines on the flanks of a structural uplift known as the Martinsville dome expose practically the same geologic section from the base of the LaSalle cyclothem down to the upper part of the Gimlet cyclothem. These ravines are in the southwest portion of Clark County, in T. 9 N., R. 14 W., secs. 2, 3, and 10, south-southeast of Casey, Illinois. One of the two creeks flows eastward from the E. ½ sec. 3 into the SE. ¼ sec. 2 where it enters North Fork Creek. The other ravine is about a mile south of sec. 3 in the E. ½ sec. 10. This creek also flows eastward into North Fork Creek.

The following geologic section may be seen in these two creek valleys (8)[3]:

	Thickness	
	Feet	*Inches*
LaSalle cyclothem		
Sandstone, thin-bedded, basal member of this cyclothem	6	
Macoupin cyclothem		
Shale, brownish-gray, very slightly silty, laminated, closely jointed, small ironstone concretions	10–15	
Limestone, nodular in part with abundant shell fragments, expecially *Ambocoelia*		8
Shale, medium dark gray, very fossiliferous with *Ambocoelia*, *Phanerotrema grayvillensis*, and *Chonetes*	2	6
Shale, black, thinly laminated, rather brittle, with a few fossils	2	
Coal		9–10
Underclay, medium dark gray to olive gray, with some calcareous nodules in lower 18 inches	7–9	
Shale, yellowish-brown to bluish-gray, nonsilty to slightly sandy	5	6
Coaly streak, not persistent		⅛
Underclay, medium gray, sandy		6–18
Shale, gray, sandy, soft	3	
Sandstone, shaly and thin-bedded, and sandy shale	10±	
Flannigan cyclothem		
Shale, gray, soft, silty to slightly sandy, with large flattened ironstone concretions in lower part	20±	
Coal	1	
Underclay, olive green to greenish-gray, with some slickenside surfaces and calcareous nodules	6	
Limestone, impure, nodular, "fresh-water" type	1	
Shale, light bluish-gray, very sandy with irregular bedding		6
Sandstone, fine grained, micaceous, and sandy shale, grading into underlying shale	4–5	
Shoal Creek cyclothem		
Shale, greenish-gray to medium-gray weathering a rusty brown color, lower 6 feet containing medium to large calcareous ironstone nodules	15	
Limestone, weathering a rusty brown color, massive, dense to crystalline, conglomeratic in upper 1 foot, very fossiliferous with crinoid stems in abundance (fig. 3)	2⅓–3	

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[3] Numbers in parentheses refer to locations of outcrops as shown on Plate I and described in the Appendix, p. 31.

	Thickness	
	Feet	*Inches*
Shale, greenish-gray, fossiliferous with black pebbles at base		4–8
Shale, black, with gray clay streaks, hard, somewhat slaty, fossiliferous, with gypsum crystals		4
Coal, rather shaly		1
Underclay, gray to greenish-gray with slickensides in upper part and secondary calcite crystals in lower part	4–7½	
Limestone, very impure, nodular "fresh-water" type	1	
Sandstone, buff to medium gray, fine grained and micaceous, with some sandy shale	4–5	
Shale, drab to greenish-gray, very sandy	15	
Sandstone, thin-bedded to shaly	10	
Collinsville cyclothem		
Limestone, weathering reddish brown, crystalline, sandy in places, with irregular upper surface, fossiliferous with *Composita* and *productids* most abundant	1	10
Shale, greenish-gray to drab	2	
Sandstone, thin-bedded	6	
Shale, sandy, light bluish-gray, with concretions	20–25	
Sandstone, thin-bedded to shaly, with much carbonaceous material	8	
Trivoli cyclothem		
Limestone, impure, nodular, very fossiliferous, with *Ambocoelia*	1	
Shale, black, slaty, fossiliferous with *Composita*, *Ambocoelia*, etc	1	
Shale, black, slaty to flaky with *Rhombopora* and crinoid stems	1	
Coal		8–10
Underclay	2±	
Shale, gray, sandy	4	
Sandstone, hard, calcareous, thin-bedded, shaly, and sandy shale	15–20	
Gimlet cyclothem		
Shale, gray, silty, with spheroidal weathering and flat ironstones	30	

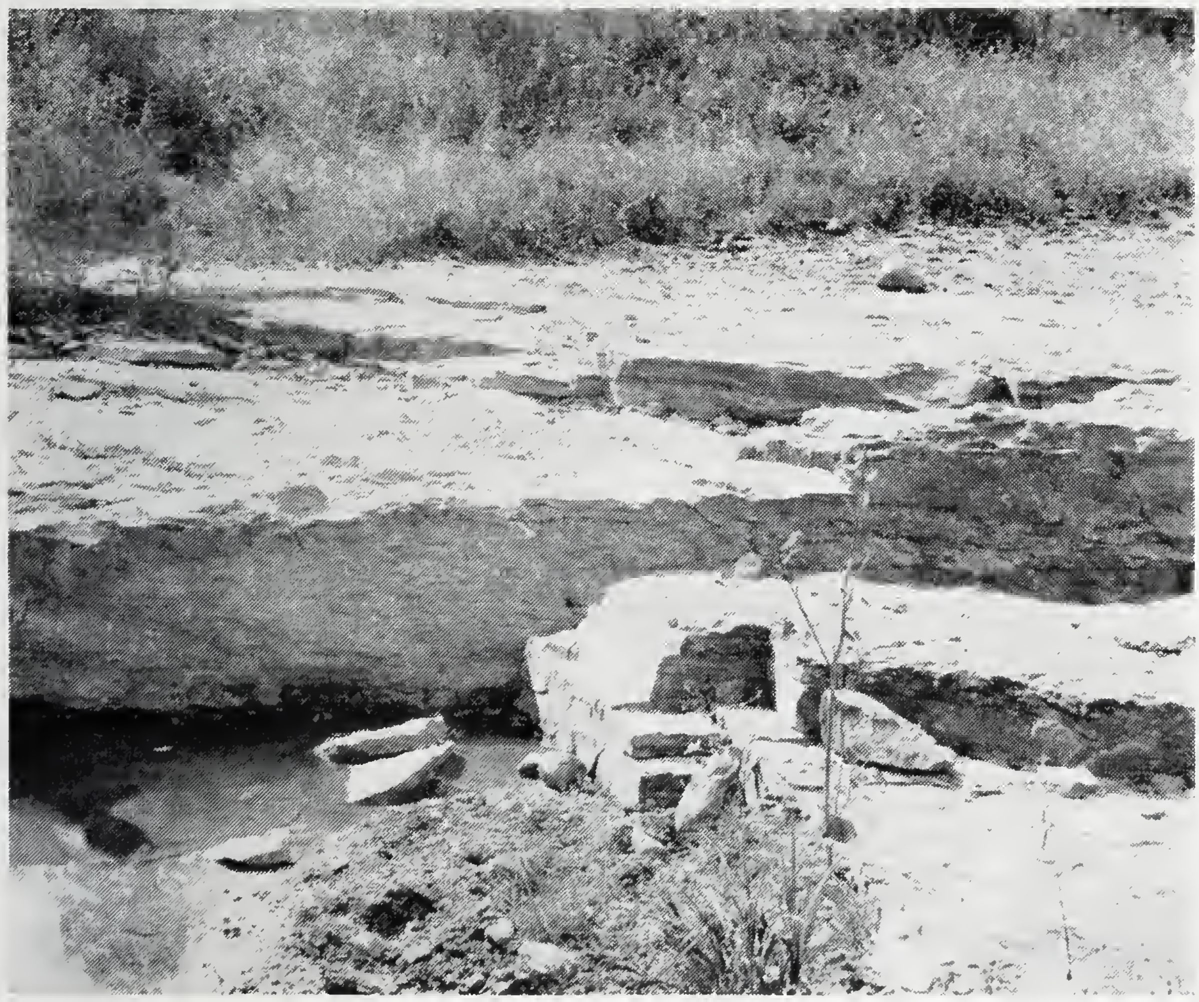

Fig. 3.—Shoal Creek limestone, NW. ¼ SE. ¼ sec. 3, T. 9 N., R. 14 W., Clark County.

Macoupin Cyclothem.—The exposures of the Macoupin cyclothem are confined to the eastern portions of this area. Outcrops may be seen in Clark, Crawford, and Lawrence counties, and also in Sullivan County, Indiana, which borders the Wabash River just east of Crawford County (fig. 2).

The Macoupin cyclothem varies considerably in thickness and lithology in this area, some of the members being absent in places. This cyclothem lies above the Flannigan and below the LaSalle cyclothems.

Probably the most diagnostic member of the Macoupin cyclothem in this area is a black sheety to slaty shale, a few inches to 2 feet thick, with a very fossiliferous white to buff colored limestone above it and coal below. Although the black sheety shale is present in most places it is locally absent where one would normally expect to find it well developed.

The basal member of the Macoupin cyclothem in eastern Clark County is sandstone, the upper few feet of which is calcareous. The lower part of the sandstone is thin-bedded and cross-bedded and in places is shaly and grades into sandy, micaceous shale. In western Clark County and in Lawrence County this basal member is gray, sandy, soft shale. At locality (22) in Lawrence County (Pl. I and Appendix) the underclay is absent and the shale below the coal is nonsilty at the top and contains poorly preserved plant remains. This shale grades downward into a greenish-gray, fine grained, irregularly bedded sandstone, the top of which is about 17 feet below the base of the coal.

Above the Macoupin basal sandy shale and sandstone and below the underclay in Clark County at locality (8) (Pl. I) there has been recognized locally a clayey to slightly sandy shale about 6 feet thick with an underlying coaly streak and sandy underclay, as described above in the discussion of the Martinsville dome area. The probable equivalent of this bed may be seen below the Macoupin underclay at the Merom bluff locality (14) in Sullivan County, Indiana, where ironstone concretions are present in a dark clayey shale. About 7 feet below the underclay there is a light blue clayey shale with calcareous nodules. These local occurrences are above the basal sandstone of the Macoupin cyclothem and probably represent local irregularities of deposition, the beds having some characteristics of the marine portion of a normal cyclothem.

The Macoupin underclay, where present, is medium gray to dark gray, and carries a few limestone nodules in the lower part at locality (8) and root traces at locality (17). In Lawrence County the underclay is thin or absent, as shown on Plate I, columnar sections (20), (21), (22), and (23).

The Macoupin coal in Clark County is about 6 inches thick at localities (8) and (9), although at (10) it is only one inch thick (Pl. I). At locality (13) in Crawford County the coal, if present, is below water level. At (16) the top of the coal may be seen in an old surface mine where the coal is said to be 20 inches thick. Across the Wabash River to the east it is 1½ feet thick at locality (14). In the extreme east-central part of Crawford County at (17) the coal is one foot thick. It thins southward, and is absent or ranges from a trace to 8 inches thick in Lawrence County, as shown in sections (20), (21), (22), and (23) on Plate I. At locality (23) the coal is slaty and canneloid.

As has been mentioned, a persistent black sheety to slaty shale is characteristic in the Macoupin cyclothem in this area. In certain localities this black shale has a marine limestone both above and below it (Pl. I, columnar sections 17, 20, 21, 22, and 23). At each of these horizons the limestone is very earthy and nodular or is represented by limestone nodules in a clay matrix. It is also very fossiliferous. At locality (16) in the old surface mine exposure the black sheety shale occurs directly below a 4-foot bed of massive limestone and rests upon the coal. About 20 feet away, in the same exposure, the black shale is absent and a dark bluish-gray shale containing small gray, hard, elongate limestone concretions occurs in its place between the limestone and the coal. The black sheety shale is also absent in locality (15) in creek bed exposures both north and south of the road. At this locality the dark gray shale between the limestone and the coal contains the same small elongate limestone concretions, but also contains oval septarian concretions as large as 1½ feet in diameter. The hard concretions were also found at locality (22). Conodonts and fish scales are present in the lower part of the black shale at locality (17) and a few poorly preserved fossils at locality (8). In Lawrence County (23) on the south side of Raccoon Creek two slaty shales were noted, one directly above the coal and one directly above the intervening limestone. An 8-inch black silty shale between the lower slaty shale and the limestone contains a species of *Aviculopecten* at this locality.

The limestone found above the black sheety to slaty shale varies from a massive bed to one composed mainly of calcareous fossiliferous nodules. It is a very fossiliferous limestone, usually containing numerous crinoid stems and *Ambocoelia. Dictyoclostus, Linoproductus, Lophophyllum,* and fenestellid bryozoans are present at locality (15) and at some other localities. The limestone commonly weathers a rusty brown to buff color.

The shale directly above the limestone is usually nonsilty, gray to dark gray in color, and is commonly calcareous, containing fossils similar to the underlying limestone. Small ironstone concretions or spalls are found in this upper shale.

LaSalle cyclothem.—Exposures of strata belonging to the LaSalle cyclothem may be seen in Coles, Clark, Crawford, Lawrence, and Richland counties, Illinois, and in Sullivan county, Indiana (fig. 2 and Pl. I). In the geologic section the LaSalle lies above the Macoupin and below the Cohn cyclothems.

The type locality of the cyclothem here known as the LaSalle is in LaSalle County in the northern part of the State. At the type locality there is only one marine limestone in this cyclothem, but in Coles and Clark counties, in the northern part of the area under discussion, there are two marine limestones, recognized in the field as "upper" and "lower" LaSalle, whose presence constitutes a problem (figs. 4 and 5).

These two limestones have been recognized in well logs in several counties to the west of Coles County. South of Clark County only one of these limestones, which is thought to be the "lower" LaSalle, is present on the surface.

The two LaSalle limestones outcropping in Coles and Clark counties are much alike in appearance. Where both are present neither one of the limestones is included in a series of strata which constitute a complete cyclothem. The "upper" limestone has no underlying sandstone and the "lower" limestone does not have much shale above it. Columnar sections (6) and (7) (Pl. I) show these characteristics. In Clark County the thin coal locally present between the two limestones suggests that the "upper" limestone should be included in a separate cyclothem, inasmuch as the strata below the limestone may be well developed in localities outside of this area. The "lower" limestone, where outcropping in those counties south of Clark County, generally overlies a thick and persistent coal, and is overlain by a well developed upper shale.

The problem of the LaSalle cyclothem resolves itself into the following points: (1) the absence of the "upper" limestone south of Clark County should be explained; (2) subsurface studies in adjoining counties may reveal that these two limestones should be included in separate cyclothems; (3) one of these two limestones should, if possible, be definitely correlated with that at the type locality in LaSalle county; and (4) if this correlation is possible it may be advisable to include one of the two limestones in a differently named cyclothem, or if this correlation is not possible both limestones should probably be renamed, other than LaSalle, into two separate cyclothems for this area. The fact that these two limestones crop out together only in two counties in this area has caused the writer to include them, where present, in one cyclothem, tentatively known as the LaSalle cyclothem.

The LaSalle cyclothem is characterized by a generally persistent coal below the lower limestone throughout this area (Pl. I). The limestone is massive in character in the northern part of the area, and where two limestones occur they are usually subcrystalline to brecciated in appearance. In the southern part of Crawford, Lawrence, and Richland counties the limestone, where exposed, is bluish-gray and in places is quite nodular. It is somewhat fossiliferous in the northern part of this area and very fossiliferous in the southern part. In contrast to the Macoupin cyclothem no black slaty shale has been found associated with the LaSalle in this area.

The basal sandy shale and sandstone of the LaSalle cyclothem in this area has no characteristics peculiar to it alone, although it is usually quite calcareous where overlain by a "fresh-water" limestone.

"Fresh-water" limestones have been found below the LaSalle underclay at localities (17) and (19) in Crawford County (Pl. I). "Fresh-water" limestones have been designated as such because where present they occur in the lower or continental portion of the cyclothem, and because they are often nonfossiliferous or contain nonmarine fossils, such as *Spirorbis* and certain species of nonmarine fish. The "fresh-water" limestone of the LaSalle cyclothem is apparently nonfossiliferous, hard, impure, and nodular, and is about 1½ feet thick. This horizon is often recognized by nodules the size of the fist in a clay or shale matrix. Where massive and sandy it often grades laterally into a very calcareous sandstone with a knobby or uneven upper surface, as is commonly found in the vicinity of locality (19).

The LaSalle underclay is usually silty and contains small limestone pellets and nodules. Where it is nonsilty, as at localities (17) and (24), it usually contains abundant plant stem impressions.

The LaSalle coal below the lower limestone is generally of good quality, hard and blocky in structure. In Crawford, Lawrence, and Richland counties it contains much clarain and vitrain which gives it a characteristic bright luster. It breaks into rectangular blocks. Its thickness averages about 1½ feet.

The shale below the lower LaSalle limestone and above the coal varies in thickness and is not present throughout the area (Pl. I, columnar sections 6, 7, 12, 13, 14, 17, 19, 24, and 25). In the northern part of Crawford County at localities (12) and (13), where the limestone is massive, the underlying shale is light to medium gray, weathering brownish gray, and is usually very sandy at the top becoming nonsilty towards the base. At locality (13) plant stem impressions are present about 4 feet from the top of the shale and are very abundant at the base just above the coal. At locality (13) this shale between the limestone and the coal is 17 feet thick. It thins to 2 feet within a distance of 9 miles to the Merom bluff locality (14). In southern Crawford, Lawrence, and Richland counties the shale is generally absent where the limestone is massive. At those localities where the limestone is more earthy to nodular in appearance the underlying shale is light to dark gray, very fossiliferous, and contains abundant limestone nodules similar to the limestone found above it. In many places the limestone grades laterally into this type of bed.

The LaSalle limestone is well exposed east of Charleston along the Embarrass River in Coles County, in several places in the east half of Clark County, along tributaries to North Fork Creek in the west part of Clark County, and at the following locations near Casey: (1) in the east-central part of sec. 28, T. 10 N., R. 14 W. (fig. 4); (2) along the south line of this same section; and (3) in the N. ½ sec. 8, T. 9 N., R. 14 W.

Good exposures of the "lower" LaSalle limestone may be seen in the east half of Crawford County, Illinois (fig. 5), and at the Merom bluff locality (8) in Sullivan County, Indiana. West of the town of Flat Rock, in the southern part of Crawford County, there are several outcrops along the small streams.

In southwestern Lawrence County along the west county-line there are a few exposures of the LaSalle. There are also several excellent exposures in small coal stripping pits in the extreme southeastern part of Richland County.

In Coles County (6) and in Clark County (7) the two "upper" LaSalle limestones may be seen (Pl. I). In this area it is only in these two counties that the two limestones have been recognized. In Coles County (6) there is a medium gray, finely silty shale 3½ feet thick separating the two limestones. The upper one foot of this shale locally contains ironstone concretions; the lower part contains small limestone nodules. The uppermost limestone is 8 feet thick, being light gray, hard, and dense, with thin irregular limestone beds at the top and more massive beds below. In places this limestone is subcrystalline and brecciated. It is fossiliferous, and at some places the crinoid stems are large and very abundant. It also contains *Linoproductus*, *Spirifer*, and other brachiopods. The lower limestone is about 3 feet thick with a very irregular base. It is quite nodular in the lower part and large limestone nodules extend down into the underlying shale.

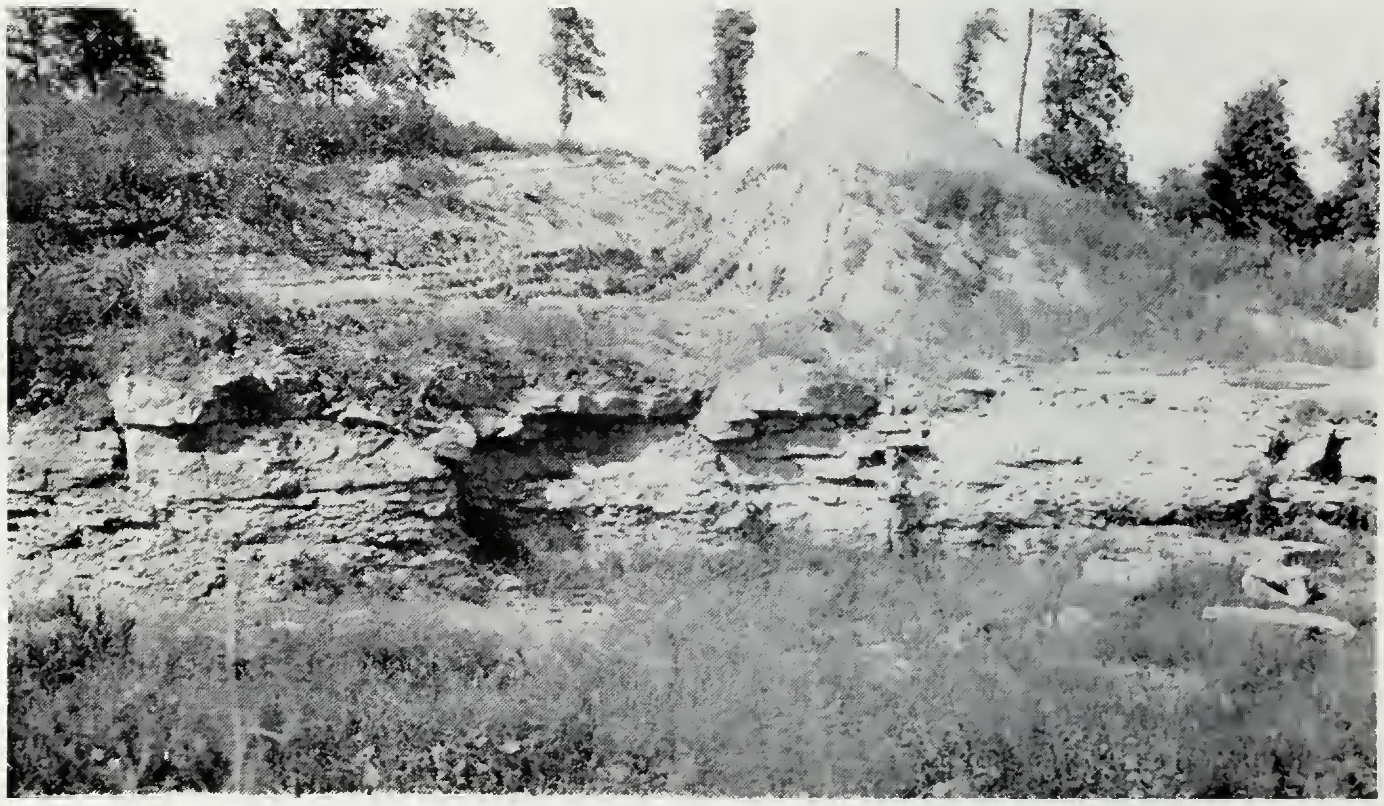

Fig. 4.—LaSalle limestone at quarry in middle of section along south line sec. 28, T. 10 N., R. 14 W., Clark County.

The two limestones are present in several exposures in Clark County, although the lower limestone is considerably thicker and coal lenses occur between the two limestones. In the west portion of Clark County in the S. ½ sec. 28, T. 10 N., R. 14 W., the two limestones attain a total thickness of 23 feet, and are separated by one foot of light gray, poorly bedded, plastic clay or shale bearing gypsum crystals. This clay or shale zone is about 4 feet from the top of the limestone in the quarry face. North of this exposure in the east center of the same section about 14 feet of what is thought to be the lower limestone is exposed in an old quarry face along the stream cut. Below this limestone is a greenish to brownish-gray, calcareous shale 1 foot 8 inches thick, below which is 1 inch of coal, 2 inches of underclay, and 4 feet of very sandy shale to shaly sandstone with abundant plant material and some well preserved leaves in the upper part.

In the eastern portion of Clark County in the northeast part of sec. 1, T. 11 N., R. 12 W., the shale and clay interval between the two limestones is about 5 feet, which includes a 3-inch layer of coal. This section is shown in (7) (Pl. I) which includes also the exposure further south in the west-central part of sec. 12, T. 9 N., R. 12 W. At this locality the interval between the two limestones has increased to more than 10 feet, the included coal bed having likewise thickened to about 8 inches. At these localities the upper limestone is medium gray to grayish-white, hard, subcrystalline with a brecciated appearance, thin-bedded in the upper one foot and massive below. Crinoid stems are very abundant in the upper portion, and *Composita* is common in the lower part. The lower limestone is grayish-white, very hard, massive, and breaks with a splintery fracture. Crinoid stems are present but not abundant.

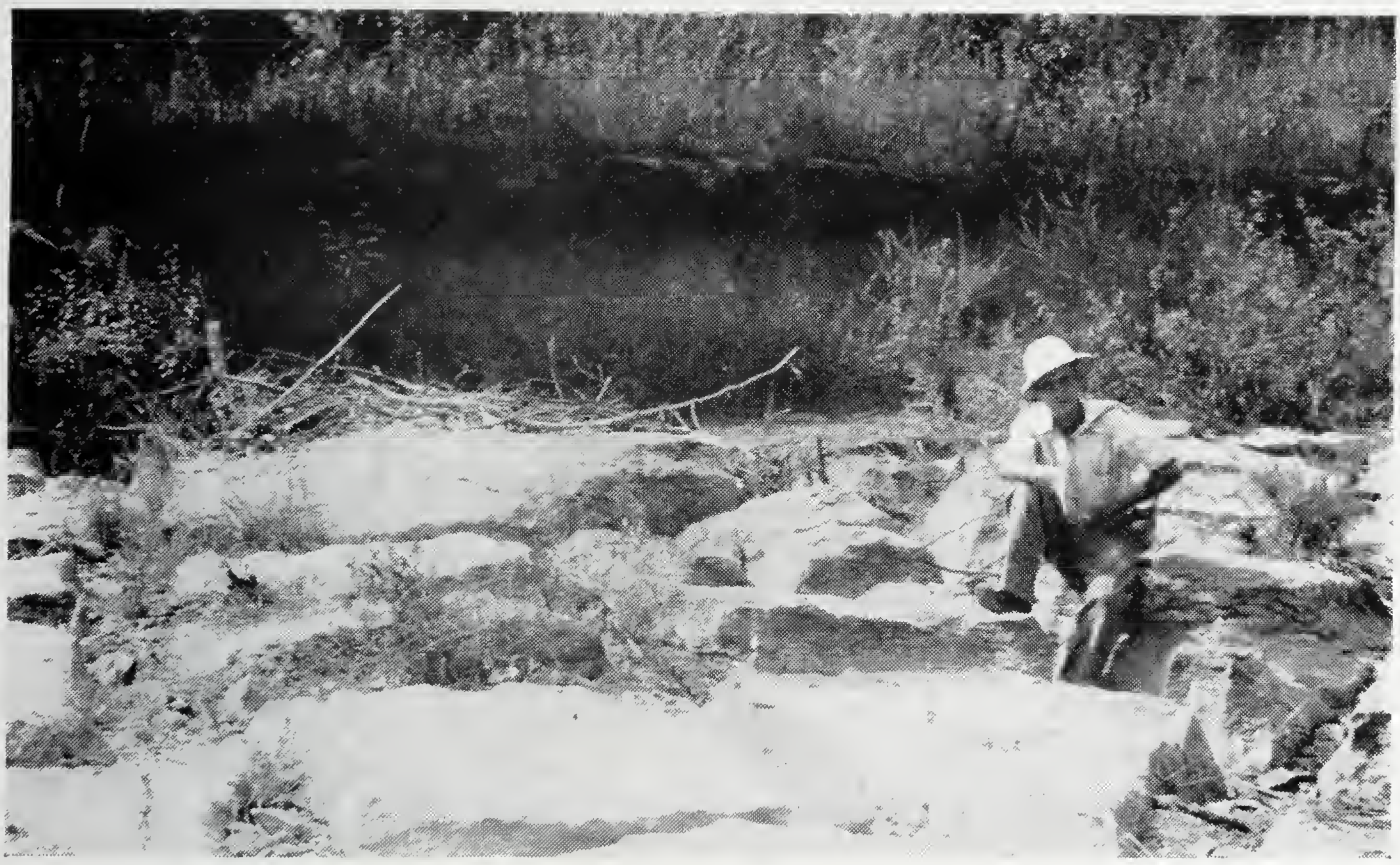

Fig. 5.—Lower LaSalle limestone showing solution joints, in bed of creek in the NE. ¼ sec 9, T. 8 N., R. 12 W., Crawford County.

Southeast of these Clark County exposures in the extreme northeast part of Crawford County, localities (12) and (13) (Pl. I), the lower limestone of the LaSalle cyclothem has thinned to 5 feet. It is light bluish-gray, weathering brownish-gray on the interior and white on the exterior. It is hard, somewhat brittle and splintery, and weathers into large rectangular blocks. Crinoid stems and small corals are present although not abundant. This limestone contains productids at the Merom bluff locality in Sullivan County, Indiana (14) where it is directly overlain by 20 feet of Merom sandstone. At locality (17) east of Palestine, Crawford County, the limestone is about 3 feet 8 inches thick and is dark gray to bluish-gray. At this locality it is earthy and nodular with abundant crinoid stems and worm casts. At localities (18) and (19) (Pl. I) west of Flat Rock, Crawford County, the limestone is 2½ feet to 3½ feet thick, dark gray to bluish-gray in color. Although it is massive in many exposures it is earthy and very nodular in others, much in contrast to those exposures in northern Crawford and Clark counties. Exposures of the LaSalle limestone in southwestern Lawrence County and in Richland County to the west show the limestone generally to be from 2½ feet to 3 feet thick. The limestone in some exposures is a dark gray to bluish-gray bed, while some outcrops of the limestone are earthy and nodular to shaly. One may observe the complete disappearance of a massive bed within a distance of 75 feet at the same locality.

The upper shale of the LaSalle cyclothem is generally medium gray to olive gray, slightly silty to sandy, well bedded, and commonly contains large flat ironstone concretions near the base.

Cohn Cyclothem.—The Cohn cyclothem is a small cyclothem occurring above the LaSalle and below the Bogota cyclothems in this area. It has been recognized at two localities in Clark County and at one in Richland County (fig. 2).

The type locality is about two miles northwest of Cohn in northeastern Clark County, in the NE. ¼ sec. 1, T. 11 N., R. 12 W. A small showing of the upper part of this cyclothem may also be seen at the base of a bluff along a small stream in the N. ½ sec. 21, T. 10 N., R. 12 W., in the southeast portion of the same county. These two geologic sections are included in Clark County (7) (Pl. I).

The total thickness of the Cohn cyclothem exposed in southeastern Richland County at locality (24) is only 7½ inches. This exposure is along a small stream in the central part of the E. ½ sec. 11, T. 2 N., R. 14 W.

No basal sandy shale or sandstone member of the Cohn cyclothem is present at any of the three localities described above.

The Cohn underclay at the type locality in Clark County is 5 feet 8 inches thick. It is gray in color becoming greenish-gray in the lower 1 foot, and contains small, round, calcareous concretions in the lower part. At locality (24) in southeastern Richland County the underclay is only 1½ inches thick.

The Cohn coal is very thin where present in this area, being 2 inches thick at the type locality and only 1 inch to 1½ inches thick at the locality in Richland County. The coal is very shaly and grades into a shale with thin coaly lenses.

At the type locality in Clark County the shale above the coal is black, flaky, and contains *Ostracodes* in the lower part. This shale is 1 foot thick. Above it is 1 foot 3 inches of light to medium olive-gray, soft shale, which contains small, weathered, ferruginous concretions. *Ostracodes* and coprolites as much as an inch in length, are present in sec. 21, T. 10 N., R. 12 W., Clark County. In Richland County the shale above the coal is dark gray at the base and grades upward into the basal sandy shale and sandstone of the Bogota cyclothem.

Bogota cyclothem.—Exposures of strata belonging to the Bogota cyclothem may be seen in Coles, Clark, Crawford, Richland, and Jasper counties (fig. 2).

The Bogota lies above the Cohn and below the Newton cyclothems. It actually includes two separate cyclothems, which are here referred to as upper and lower Bogota. Strata probably equivalent to the upper and lower Bogota also crop out in counties to the south and west of this area. The type locality of the upper Bogota is along Muddy Creek in the extreme southwestern part of Jasper County, about five miles southwest of Bogota. Although there are several exposures of the lower Bogota in this area, the writer has not given this group of strata a separate name because he believes that exposures outside of this area will later serve better as type localities.

The lower Bogota is characterized by a thin coal in Coles and Crawford counties (Pl. 1). This coal thickens southward and is as thick as 2 feet in Jasper and Richland counties. There is no overlying marine limestone although the shale above the coal is somewhat fossiliferous. Where the Cohn cyclothem is present below the lower Bogota in Clark County there is an intervening "fresh-water" limestone.

The upper Bogota is characterized by its thick black sheety to slaty shale in which are found large, hard, oval or flat, calcareous concretions. There is a marine limestone above and often below the black sheety shale. The underlying coal, if present, is usually only 1 inch to 2 inches thick. The underclay is quite persistent and thick. There are commonly one or two "fresh-water" limestones in the lower part of the upper Bogota cyclothem.

The basal member of the lower Bogota is thin-bedded and shaly sandstone in the lower part, grading upward into sandy shale near the top.

In Clark County (7) there is no basal sandstone. At this locality the medium gray, hard, massive to nodular "fresh-water" limestone contains *Spirorbis* and probably represents the base of the lower Bogota. Between this limestone and the underclay above is 2½ feet of shale which contains *Ostracodes* and small calcareous pebbles.

The lower Bogota underclay is thin in Coles County (6) (Pl. 1), and is dark gray to black containing root traces and carbonaceous material. It also contains root traces in Richland County (26) and (27), being 2 feet thick at locality (27). In Clark and Crawford counties, (7) and (11), the underclay is more than 4 feet thick, is finely silty, and contains gray, argillaceous, and calcareous pebbles. A thin limestone conglomerate zone which contains *Spirorbis* and *Ostracodes* occurs at the top of the underclay in Clark County (7).

The lower Bogota coal is thin in Coles and Clark counties and was not found at all in Crawford County at locality (11). The coal is as thick as 2 feet in Jasper and Richland counties. At localities (25), (26), and (27) it is shaly and badly weathered. The coal mined southeast of Newton, Jasper County, is probably the lower Bogota.

The shale above the lower Bogota coal is commonly silty to sandy. At locality (7) in Clark County the shale is medium gray and contains ironstone concretions and plant impressions in the upper part. In the lower one foot the shale is gray to black, poorly bedded, and contains *Estheria* and *Ostracodes.* In the NE. ¼ sec. 1, T. 11 N., R. 12 W., Clark County, near water level in a small gully there is a local mud-crack zone in the shale about 6 inches above the coal. The cracks are filled with iron carbonate and the shale between the cracks contains *Estheria.* At locality (26) in Richland County the shale is sandy to silty and contains ferruginous layers in the upper part. The lower 2 feet is nonsilty and soft and flaky. In this lower part one species of *Aviculopecten* was found.

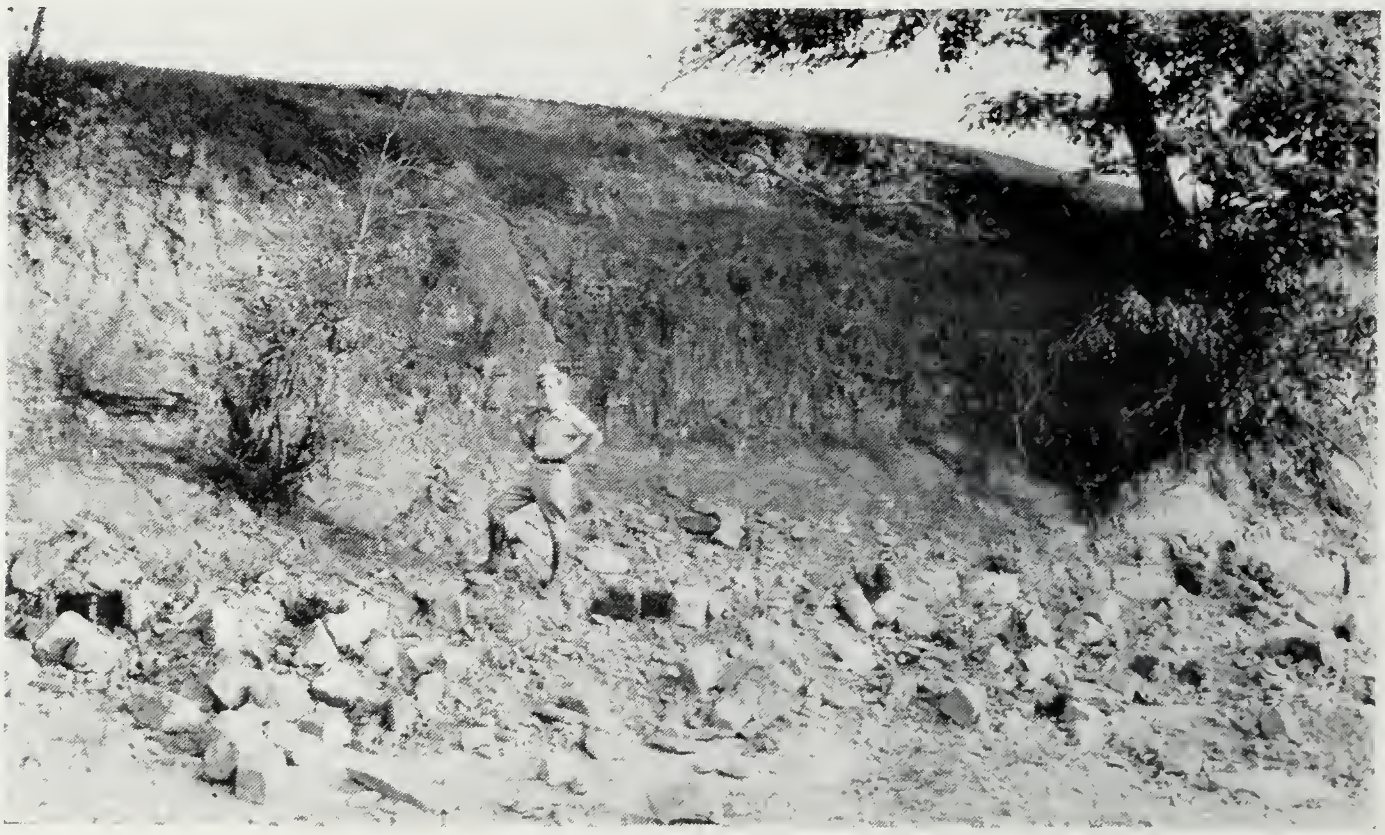

Fig. 6.—BOGOTA "FRESH-WATER" LIMESTONE SHOWING CONCHOIDAL FRACTURE, ALONG MUDDY CREEK, NE. ¼ NE. ¼ SEC. 17, T. 5 N., R. 8 E., JASPER COUNTY.

The basal member of the upper Bogota is thin-bedded sandstone which in part is calcareous. Above this sandstone is sandy shale which becomes silty at the top. In places it is iron-stained and contains irregular ferruginous nodules in discontinuous layers, notably along Crooked Creek in the west half of sec. 27, T. 7 N., R. 10 E., in Jasper County.

The "fresh-water" limestones of the upper Bogota are found in the shale just described. Their relative position below the underclay varies considerably, as does the thickness of shale separating the two limestones where both are present.

At the type locality of the upper Bogota, Jasper County (3), one "fresh-water" limestone occurs immediately below the underclay (fig. 6). Here the limestone is only a few inches thick, dark gray, and contains shark teeth. *Spirorbis* may also be present. Three feet below this limestone is the lower "fresh-water" limestone. It is medium light gray splotched with green, hard, and breaks into irregular nodules with a conchoidal fracture. *Spirorbis* are present in the limestone. At locality (30) in Richland County the upper "fresh-water" zone is composed of abundant calcareous nodules, some being quite large. The lower "fresh-water" limestone is separated from the one above by 3 feet of greenish clay. This limestone is more of a limestone conglomerate which locally becomes very sandy (fig. 7).

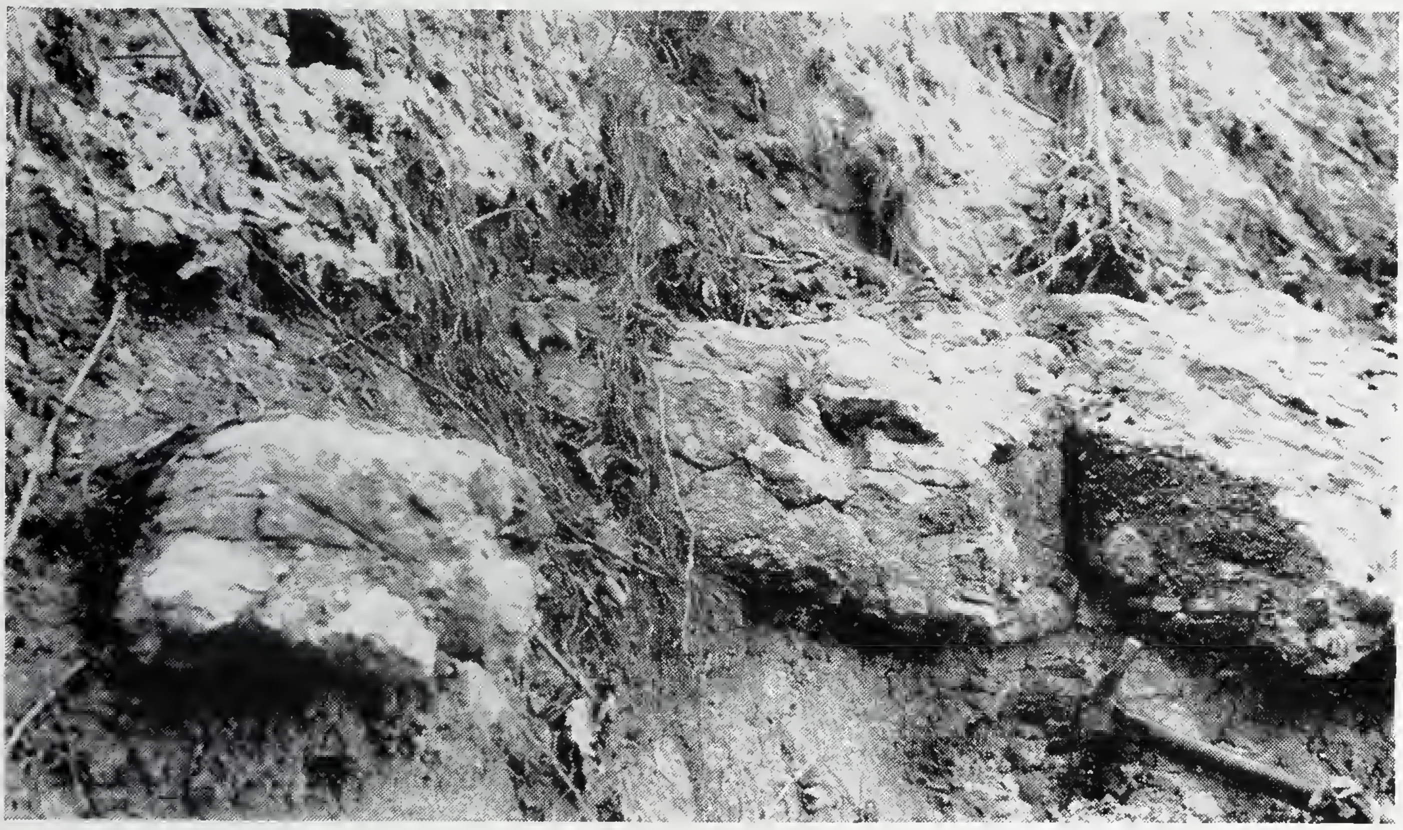

Fig. 7.—Bogota (?) "fresh-water" limestone showing conglomeratic character in the SE. 1/4 NW. 1/4 sec. 22, T. 3 N., R. 10 E., Richland County.

The upper Bogota underclay is medium to greenish-gray, sometimes weathering buff, is silty, and contains small, irregular shaped limestone nodules. It is usually massive and in some places is hard and nonplastic. It is usually 3 or more feet thick wherever exposed in this area.

The upper Bogota coal is thin and not very persistent in this area.

Where a shale occurs above the coal or underclay and below the lower marine, or "middle" limestone it is usually finely silty to sandy. At the type locality in Jasper County (3), this shale is about 2½ feet thick. It contains a sandstone lens from 4 inches to 5 inches thick which is fossiliferous in the upper part. At some localities this shale contains limestone nodules, especially where the "middle" limestone can not be definitely recognized as a persistent bed. At locality (7) in Clark County this shale is above a thin coal and contains plant leaves and stems and *Estheria.* At locality (27) in Richland County the shale above the upper Bogota underclay is dark gray, weathers brown, is finely silty, and is flaky when dry. The black sheety shale is not developed at this locality.

The "middle" marine limestone where present above the coal or underclay and below the black sheety shale, as shown in sections (3), (6), and (7) (Pl. I), is very dark gray, weathers brownish, is argillaceous, somewhat ferruginous, and in some places is very nodular. It is also fossiliferous and contains *Hustedia* and *Aviculopecten* at locality (7) in Clark County.

At locality (30) in Richland County this limestone crops out one-quarter of a mile east of the highway bridge along a tributary to Fox River. At this location it is medium dark gray, very impure and argillaceous, but hard and platy. It contains carbonaceous plant stems and *Ostracodes*. It is 1 foot to 2½ feet thick and weathers gray. The horizon of this limestone crops out one-quarter of a mile west of the highway bridge along the same stream-cut but here the bed is a black, calcareous, rather platy shale that contains *Aviculopecten*, *Solenomya*, and some carbonaceous material.

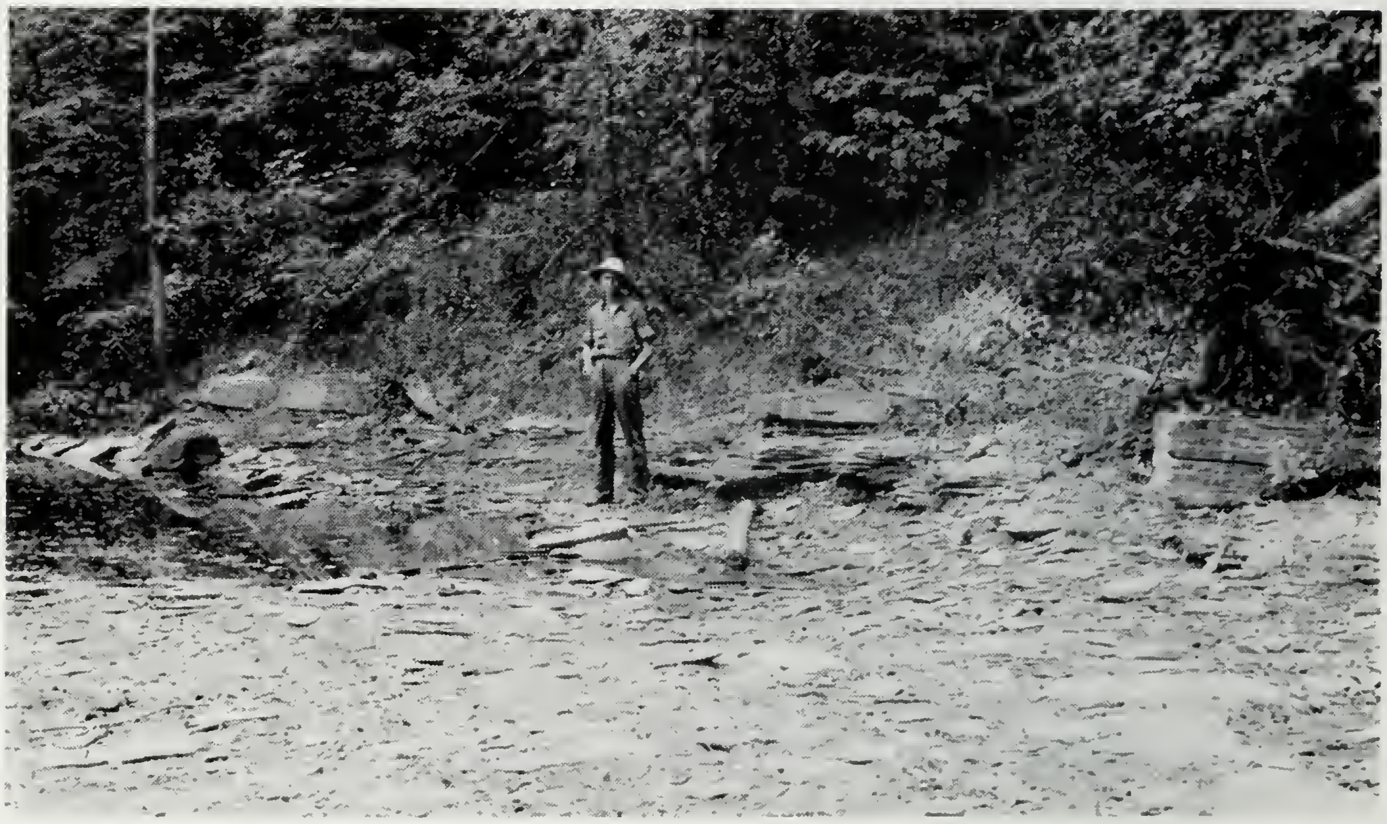

Fig. 8.—Bogota platy limestone containing ostracodes and carbonized plant stems and leaves, in the SE. ¼ sec. 15, T. 3 N., R. 10 E., Richland County. This limestone grades into a platy shale containing *Aviculopecten* and *Solenomya* half a mile to the west.

About one-quarter of a mile south of the above described exposure in the NW. ¼ sec. 22 a platy limestone 2½ feet thick is quarried in a small gully. It contains carbonaceous plant stems and *Ostracodes* and is very similar to the platy limestone east of the highway bridge in sec. 15, T. 3 N., R. 10 E. as shown in (30) (Pl. I). About 75 yards east up the gully from the platy limestone is a very nodular, ocherous, and conglomeratic "fresh-water" limestone containing *Spirorbis* (fig. 8). No evidence of a black sheety shale can be found along the gully between these two limestones. The platy limestone dips to the north and west. It is suggested that this platy limestone is the same as the limestone or its equivalent platy shale below the black sheety shale and that the ocherous, nodular "fresh-water" limestone is the same as the nodular "fresh-water" limestone below the underclay that crops out at locality (30).

The shale above the "middle" limestone horizon and below the black sheety shale of the upper Bogota is commonly dark gray to black becoming lighter towards the base; it is well bedded, flaky in part, and contains small, irregular, rounded and flattened limestone or ironstone concretions. It is fossiliferous, containing *Estheria,* fish scales, *Ambocoelia,* and small productids.

The characteristic black sheety to slaty shale of the upper Bogota is commonly 4 feet or more thick in this area. At some places the large oval or flat, hard, calcareous concretions are more numerous than at other places. The best exposure of the sheety shale and large concretions is in Richland County (30) just west of the bridge on Illinois Highway 130. One concretionary mass in the creek is about 1 foot wide and 15 feet long. The well exposed sheety shale at this locality is as much as 7 feet thick with abundant calcareous concretions (fig. 9).

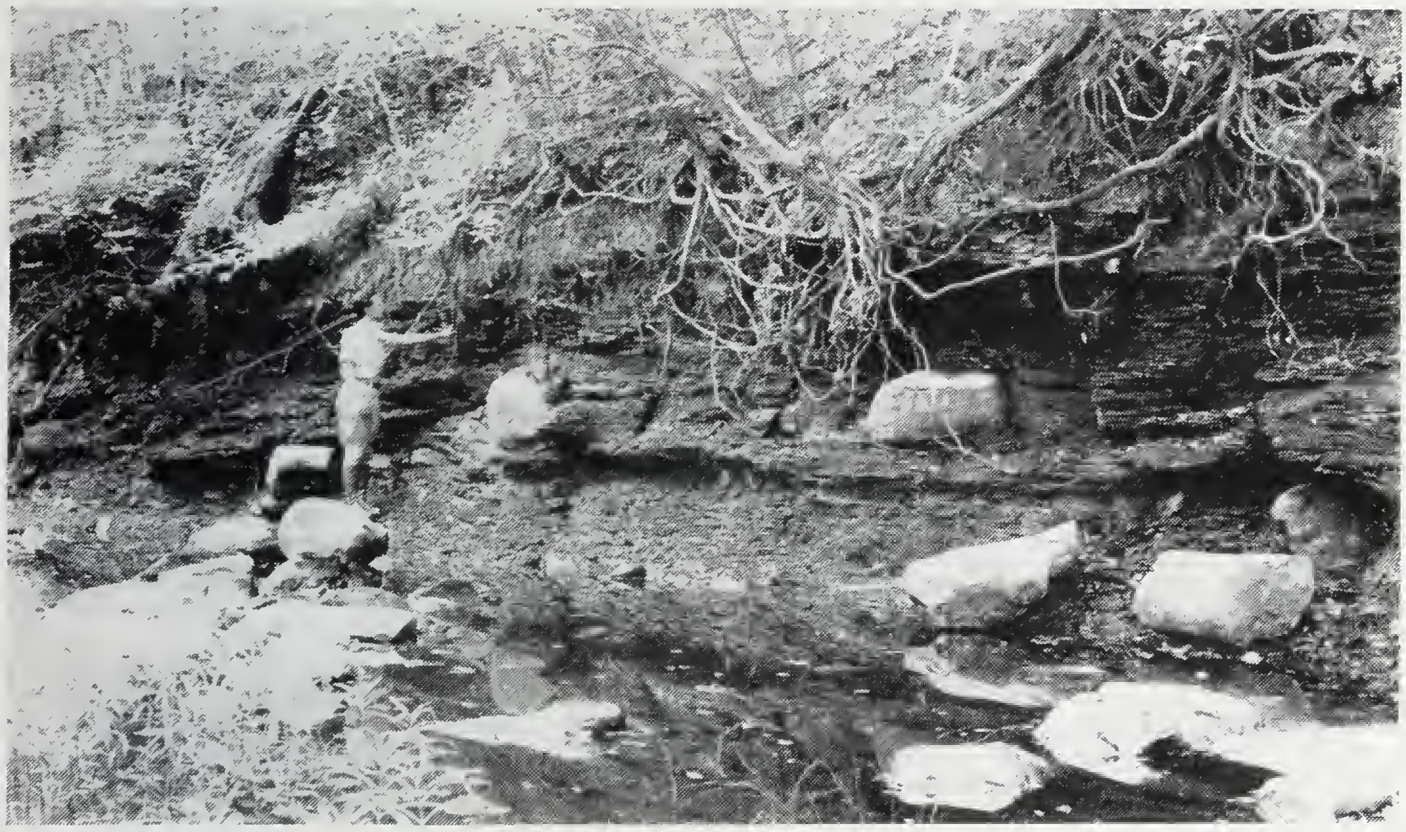

Fig. 9.—Bogota slaty shale containing large calcareous concretions, west of highway bridge, south line of sec. 15, T. 3 N., R. 10 E., Richland County.

The shale above the black sheety shale and below the upper marine limestone is gray to buff, poorly bedded, and contains marine fossils at the top. At the base of this shale it is black and silty where it overlies the black sheety shale.

The upper marine limestone of the Bogota is medium gray, weathers brownish, is dense, silty, and contains marine fossils, including crinoid stems, *Ambocoelia, Lophophyllum, Chonetes,* and *Aviculopecten.* In Richland County this bed may grade laterally from massive limestone into shale with abundant calcareous, fossiliferous nodules.

The upper shale of the upper Bogota is usually medium to dark gray to drab, silty to sandy, and contains beds of nodular ironstone concretions. In Jasper County the shale is quite sandy and at locality (4) it contains sandstone beds which carry marine fossils, including crinoid stems, bryozoa, and brachiopids. The shale often contains marine fossils near the base where it occurs above the upper limestone. At locality (30) in Richland County, *Ambocoelia, Chonetes,* corals, gastropods, and other marine fossils are present in the lower part of the shale.

Newton cyclothem.—Strata belonging to the Newton cyclothem may be seen in Cumberland, Jasper, and Richland counties (fig. 2). It occurs above the Bogota and below the Greenup cyclothems in the geologic section.

The type locality of the Newton is along Crooked Creek, about 4 miles east and a little north of Newton, Jasper County. Exposures can be seen along Crooked Creek and in gullies leading down to the creek in secs. 15, 16, 22, and 27, T. 7 N., R. 10 E. The geologic section is shown in (4), Plate I. These are the best exposures of the Newton cyclothem in this area.

The Newton is characterized by a black sheety to flaky shale which overlies a gray, earthy, fossiliferous limestone. Two "fresh-water" limestones occur in the lower part of the cyclothem at the type locality. In the lower one *Spirorbis* is very abundant. Both limestones are not always seen at less extensive outcrops. No marine limestone has been found above the black shale in this cyclothem. Although there is an underclay there is no coal above it.

The basal member of the Newton cyclothem is mainly sandy shale with some thin-bedded sandstone which is calcareous in part. At the type locality this sandy shale rests upon a gray, hard, calcareous siltstone about 3 inches thick at the top of the upper member of the Bogota.

The "fresh-water" limestones occur in the sandy shale or lower portion of the Newton. They may be within a few feet of each other or may be separated by as much as 20 feet of shale and sandstone. The lower "fresh-water" limestone is gray, weathers gray to buff color, and usually contains abundant *Spirorbis.* It is fine-grained to dense, hard, with calcite streaks. It sometimes weathers into slabs or is nodular. The upper "fresh-water" limestone is a yellowish-brown color, generally nonfossiliferous, although *Spirorbis* is occasionally present. It is hard, conglomeratic, contains calcite flecks, and weathers into angular fragments.

The Newton underclay is drab to light bluish-gray. At the type locality it contains calcareous nodules with *Spirorbis* where it overlies the "fresh-water" limestone. At locality (31) in Richland County the underclay contains a few root traces in the upper part.

At the type locality, Jasper County (4), there is 2 feet of medium dark gray silty shale above the underclay and below the "middle" limestones. It is poorly bedded above and flaky below. At locality (31) in Richland County this shale is about 1 foot thick (Pl. I). In the upper part just below the limestone crinoid stems are present; in the lower part it contains carbonaceous material where it overlies the underclay.

The Newton "middle" limestone is a dark gray, very argillaceous limestone varying from 7 inches to 1 foot in thickness. It is very fossiliferous containing mostly brachiopods, many of which are crushed and broken. *Chonetes* and crinoid stems are abundant. This horizon may locally be a shale with abundant limestone nodules and fossils. At locality (31) in Richland County the limestone is very ferruginous and contains tiny calcite veinlets.

The black sheety shale above the Newton limestone varies in thickness from 1½ to 4 feet at the type locality along Crooked Creek in Jasper County. The black shale is not always sheety throughout the entire thickness. It may in part be flaky, rather soft to very hard, and slightly silty. It may also be in part well laminated and contain poorly preserved carbonaceous plant impressions. The black shale is not present above the limestone at locality (31) in Richland County.

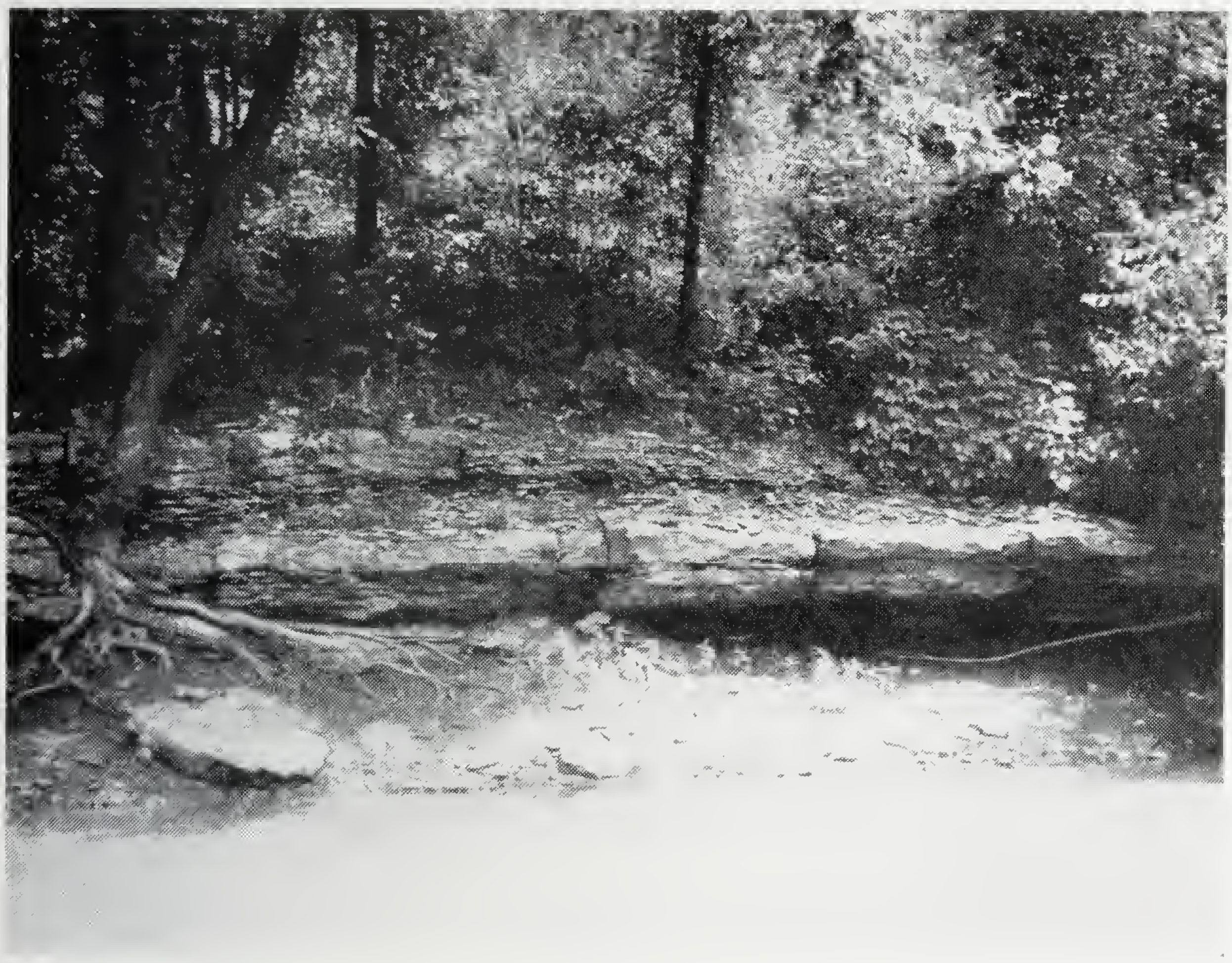

Fig. 10.—Greenup limestone, east bank of Embarrass River within sight of bridge, NW. ¼ sec. 2, T. 10 N., R. 9 E., Cumberland County.

The Newton upper shale is gray to dark gray, silty, becoming sandy at the top, thin-bedded, and contains flat oval ironstone concretions. In the NE. ¼ sec. 1, T. 9 N., R. 9 E., just northeast of Greenup in Cumberland County the first 5 feet of the shale above the black sheety shale has a distinct blocky structure and contains *Aviculopecten* and other fossils. The upper shale of the Newton cyclothem is more than 40 feet thick in places.

Greenup cyclothem.—The Greenup cyclothem lies above the Newton and below the Gila cyclothems in the geologic section. The principal exposures of strata belonging to the Greenup occur in the central western part of this area, in Cumberland and Jasper counties, and the basal sandy shale member extends southward into Richland County.

The Greenup cyclothem is characterized by a light gray, nodular to shaly, fossiliferous limestone with *Fusulina* often present in the upper part. It is underlain by massive to thin-bedded sandstone or sandy shale, and is overlain by massive, calcareous sandstone or poorly bedded shale. No beds of "fresh-water" limestone, underclay, coal, or black sheety shale have been recognized in this cyclothem in this area.

The basal member of the Greenup cyclothem is composed of thin-bedded sandstone and sandy shale which may be calcareous and massive in the upper part. It varies in thickness from a few feet to more than 25 feet in this area.

The Greenup marine limestone varies considerably in lithology but can usually be distinguished from the marine limestones of associated cyclothems by its occurrence between two shales or sandstones and by the fossils which it contains, notably *Fusulina* (see columnar sections 1, 2, 5, and 31, Pl. I.).

The Greenup limestone is exposed at several places along the Embarrass River just north of Greenup, Cumberland County, especially in secs. 2 and 3, T. 9 N., R. 9 E. A very accessible outcrop of the limestone is along the Illinois Highway 130 road-cut just south of the Embarrass River in sec. 2 where it overlies sandstone and is about 15 feet above the flood-plain of the Embarrass River (fig. 10). Four miles north of this locality the Greenup limestone outcrops on the east side of the Embarrass in the NW. ¼ sec. 2. The limestone may be seen from the bridge an eighth of a mile south of the outcrop. The limestone is light gray, weathers somewhat brownish, is quite fossiliferous, and some upper surfaces of the limestone are covered with small worm-tube casts. The shale below the limestone is silty at the top and sandy below.

The Greenup limestone is exposed at several places in T. 10 N., R. 8 E., along the northwest-southeast tributary to the Embarrass in sec. 15 and in the northeast part of sec. 16. The limestone is 2½ feet to 3 feet thick where the total thickness is seen. The upper 10 inches of the limestone is gray, weathers to a buff color, and is very fossiliferous with many *Fusulina.* This part of the limestone is well exposed along the creek just north of the road in the SE. ¼ sec. 15. The lower part of the limestone is gray, argillaceous, and fossils are not conspicuous. The upper fusulinid portion of the limestone is not everywhere present. Where it is absent the lower part weathers with a very uneven surface. Shale is found both above and below the limestone.

In southwestern Cumberland County in the road on the half-section line in the W. ½ sec. 30, T. 9 N., R. 8 E., is an outcrop of nodular Greenup limestone. Just north of this road a cross-bedded channel sandstone cuts out the limestone, and has limestone pebbles in its conglomeratic base.

In northwestern Jasper County, just south of the Cumberland County line, the limestone crops out in an east-west gully which crosses a north-south road in the northeast part of sec. 3, T. 8 N., R. 8 E. At this locality the Greenup limestone is gray, weathers gray to buff, is rather pure to somewhat earthy, and grades laterally into greenish-gray clay with limestone nodules. It also grades into the underlying calcareous sandstone. The limestone contains *Fusulina* and crinoid stems. It is also present in discontinuous outcrops up a hollow which crosses secs. 10, 16, and 21 in a southwest-northeast direction. The limestone has an uneven surface and is underlain and overlain by sandstone.

At locality (1) in Jasper County, outcrops of the Greenup limestone occur along Mint Creek in secs. 7 and 17, T. 7 N., R. 9 E., northwest of Newton. The limestone is hard, nodular, weathers gray to buff color, and is fossiliferous. Crinoid stems, echinoid spines, *Rhombopora*, and other marine fossils are present. In secs. 28 and 29, T. 8 N., R. 9 W., Jasper County, in a gully that drains eastward into the Embarrass, the limestone rests upon a calcareous, irregularly bedded, brownish weathering siltstone.

The stratum above the Greenup limestone may be a thin-bedded to a massive sandstone (columnar sections 1 and 5, Pl. I), or it may be a poorly bedded, slightly greenish shale which grades into the basal member of the cyclothem above.

Gila cyclothem.—The Gila cyclothem is a small cyclothem locally developed in the northwestern Jasper County (fig. 2). It occurs between the Greenup and the Woodbury cyclothems in the geologic section.

The Gila cyclothem outcrops in T. 8 N., R. 9 E., 1½ miles southeast of Gila, in the upper part of a hollow in the southeast part of sec. 29, as shown in (2) (Pl. I). The type locality is along Mint Creek in sec. 31, to the southwest in this same township, as shown in (1) (Pl. I). Outcrops in sec. 31 continue downstream into sec. 6 of the adjoining township to the south. The Gila cyclothem at the type locality is about 20 feet thick. It thins northeastward and is only about 4 feet thick at locality (2) in sec. 29, within about one mile.

The Gila cyclothem is characterized by a medium gray, dense and hard, thin limestone containing carbonaceous material, and an underlying coal horizon, below which is an underclay that is silty and weathers buff in the lower part. The basal member is a massive to thin-bedded sandstone which may in part be calcareous.

At the type locality (1), the Gila underclay is bluish-gray to greenish-gray and weathers buff in the lower part with a texture similar to that of loess. It is very silty, rather hard, and in some places may be described as a buff, argillaceous siltstone. It has a maximum thickness of 7 feet.

At the top of the underclay at (1) there is a locally developed 3-inch cone-in-cone structure. Above this and below a coal horizon there is 6 inches of medium gray to black flaky shale.

The Gila limestone is 1 to 4 inches thick at locality (1) and is not persistent at (2). It is medium gray, weathers nearly white, is dense, fine-grained, brittle, and contains small fragments of carbonaceous material. No fossils have been found in this limestone.

The upper shale of the Gila is medium light gray, nonsilty to silty, poorly bedded, contains a few irregular ironstone concretions and at locality (1) grades laterally into hard, calcareous siltstone slabs and grades vertically into the sandy shale of the overlying Woodbury cyclothem.

Woodbury cyclothem.—The Woodbury cyclothem is the uppermost cyclothem exposed in this area. It occurs above the Greenup cyclothem in Cumberland County and above the Gila cyclothem in Jasper County.

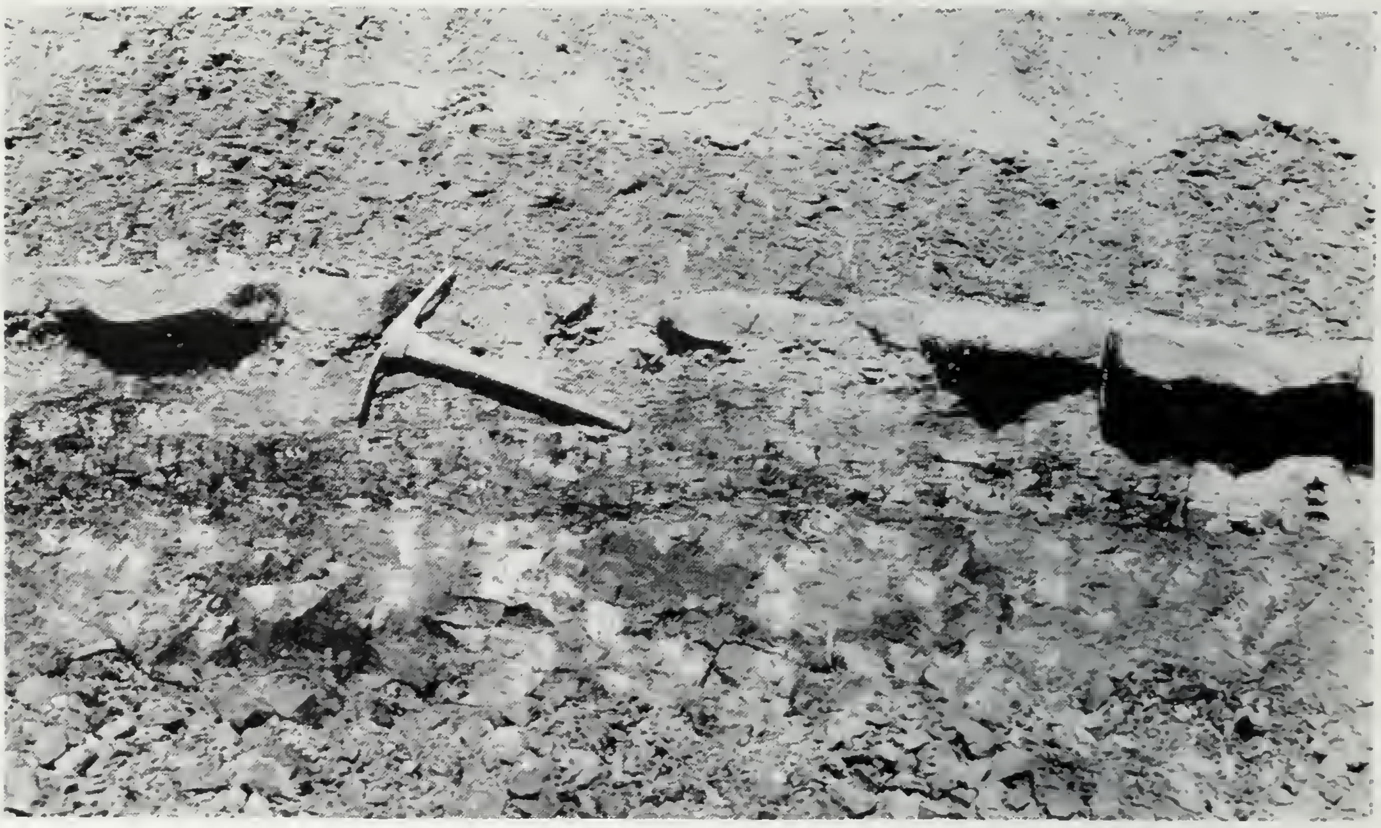

Fig. 11.—Type locality of the Woodbury cyclothem showing fossiliferous ironstone (at top of pick), 5-inch bed of coal (at base of pick), and underclay. Middle of S. ½ SE. ¼ sec. 32, T. 9 N., R. 8 E., Cumberland County.

The type locality of the Woodbury is about two miles southwest of Woodbury, Cumberland County, along Webster Creek just north of the Jasper County line (fig. 2). The best outcrop (fig. 11) is on the north side of the creek in the SE. ¼ sec. 32, T. 9 N., R. 8 E., about one-quarter of a mile west of the east section line. This geologic section is shown in (5) (Pl. 1).

The Woodbury cyclothem is characterized by a fairly persistent thin coal with a silty underclay that thickens southward. The lower part of the upper shale contains marine fossils. At the type locality there is an easily recognized very fossiliferous and calcareous ironstone band about 6 inches above the coal. Southward into Jasper County the shale is black, calcareous, and slaty.

At the type locality in Cumberland County (5), the basal member of the

Woodbury cyclothem is a calcareous, thin-bedded, locally massive sandstone which rests upon the Greenup limestone. Southward in Jasper County at locality (2) in sec. 29, T. 8 N., R. 9 E., there is no sandstone and the Woodbury underclay rests upon the upper shale of the Gila cyclothem. At locality (1) in sec. 31 of this same township the basal member of the Woodbury consists of sandy shale with thin beds of sandstone.

At locality (5) in Cumberland County the underclay is bluish-gray and sandy. It thickens southward and in Jasper County at localities (1) and (2) it is bluish-gray, quite silty, rather hard, and may be iron stained locally.

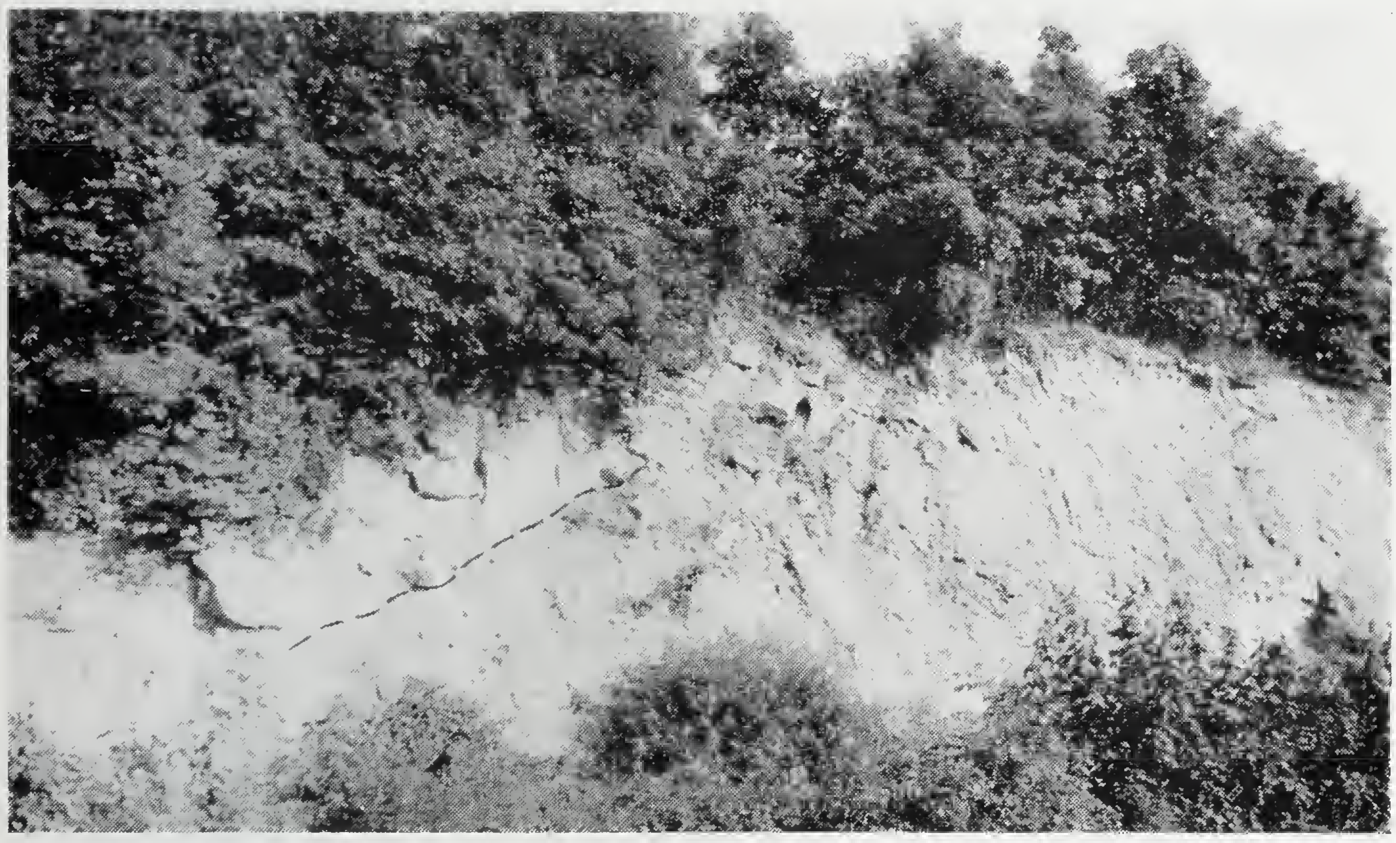

Fig. 12.—Merom sandstone channel in Newton shale, south bank of Webster Creek, NE. ¼ sec. 33, T. 9 N., R. 8 E., Cumberland County.

The Woodbury coal in southern Cumberland County at the type locality is hard, blocky, and 5 inches thick. In Jasper County it is shaly and 1 to 4 inches thick.

At the type locality there is a 6-inch shale above the coal which is dark gray to bluish-gray and fossiliferous. At some localities this shale is soft and red. It contains small calcareous nodules in the upper part and gypsum crystals in the lower part.

Southward in Jasper County at locality (2) this shale is 8 inches thick, dark gray to black, is flaky below and contains *Estheria*, *Ostracodes*, pelecypods, and carbonaceous plant stems. At locality (1) this shale is black, flaky to slaty, very calcareous, and contains poorly preserved fossils. It has the appearance in places of an impure slaty limestone.

Above this shale at locality (5) in Cumberland County is a 3-inch to 4-inch fossiliferous ironstone bed. It is medium gray and weathers a reddish, rusty brown color, and is quite hard. It contains *Schizostoma catilloides, Pharkidonotus* *pericarinatus, Meekospira peracuta, Phanerotrema grayvillenses, Lophophyllum profundum, Ambocoelia planoconvexa, Marginifera,* crinoid stems, and a species of nautiloid.

This fossiliferous ironstone bed was not found in Jasper County but the lower part of the upper shale contains similar fossils and locally contains small limestone nodules at the base.

The upper shale of the Woodbury cyclothem is gray to drab becoming darker gray below, is silty, fossiliferous in the lower part, and contains some knotty appearing ironstones.

Merom sandstone.—As stated at the beginning of this report, the sandstone which blankets a large part of this area is tentatively correlated as the Merom. In many places it lies disconformably on older formations and locally the base of this sandstone fills old stream channels (fig. 12). This sandstone is commonly brown, medium to coarse grained, friable or loose grained, cross-bedded, and it often contains irregular lenses or pockets of coal and limestone near its base.

APPENDIX

GEOGRAPHIC LOCATIONS OF COLUMNAR SECTIONS SHOWN ON PLATE I

Locality Number	County	Township	Range	Sections
(1)	Jasper	8 N.	8 E.	25, 36
		8 N.	9 E.	31, along NW.–SE. tributary
		7 N.	9 E.	6, 7
		7 N.	8 E.	12, 13
(2)	Jasper	8 N.	9 E.	28, 29
(3)	Jasper	6 N.	8 E.	29, 32, 33
		5 N.	8 E.	4, 5, 8, 9, 16, 17, 18, 20
(4)	Jasper	7 N.	10 E.	15, 16, 21, 22, 27, 28
(5)W	Cumberland	9 N.	8 E.	32, 33
		9 N.	9 E.	10, center W. ½ NW. ¼
(5)G	Cumberland	9 N.	8 E.	30
		9 N.	9 E.	3, SE. ¼
		10 N.	8 E.	15, 16
		10 N.	9 E.	2, 14, 26
(5)N	Cumberland	9 N.	9 E.	1, 2, 3
		10 N.	9 E.	36, SW. ¼
		9 N.	7 E.	35, 36
(6)	Coles	13 N.,R.	10 E.	21, 32
		12 N.,R.	10 E.	5, 6, 17, 18, 20
		12 N.,R.	9 E.	25
(7)	Clark	11 N.	12 W.	1, 2
		10 N.	12 W.	21, north central
		9 N.	12 W.	11, 12
(8)	Clark	9 N.	14 W.	2, 3, 10
(9)	Clark	10 N.	11 W.	15, 16, S. ½
(10)	Clark	11 N.	11 W.	27, W. ½
(11)	Crawford	8 N.	12 W.	5, 8, S. ½, sec. 5
(12)	Crawford	8 N.	12 W.	1, SE. ¼
(13)	Crawford	8 N.	11 W.	7, 17, NW. ¼ and west bank Wabash River
(14)	Sullivan, Ind.	6 N.	10 W.	18, river bluff at Merom
(15)	Sullivan, Ind.	8 N.	11 W.	24, east center
(16)	Crawford	7 N.	11 W.	23, east center
(17)	Crawford	6 N.	10 W.	7, NW. ¼
(18)	Crawford	5 N.	11 W.	6, SW. ¼
(19)	Crawford	5 N.	12 W.	1, 2, 3, 14, 15
(20)	Lawrence	3 N.	10 W.	9, west bank Wabash River
(21)	Lawrence	3 N.	11 W.	5, east bank Embarrass River
(22)	Lawrence	3 N.	11 W.	18, middle
(23)	Lawrence	2 N.	12 W.	26, SE. ¼
(24)	Richland	2 N.	14 W.	2, 6, 8, 11, 16, 17, 19
(25)	Richland	4 N.	10 E.	16, road-cuts in NW. ¼
(26)	Richland	4 N.	10 E.	4, road-cuts in NW. ¼
(27)	Richland	4 N.	14 W.	30
		4 N.	11 E.	30, E. ½
(28)	Richland	3 N.	14 W.	26, N. ½
(29	Richland	3 N.	14 W.	20, 21, road-cut and W. ½, sec. 21
(30)	Richland	3 N.	10 E.	15, 22, S. ¼ sec. 15, NW. ¼ sec. 22
(31)	Richland	4 N.	14 W.	8, 17

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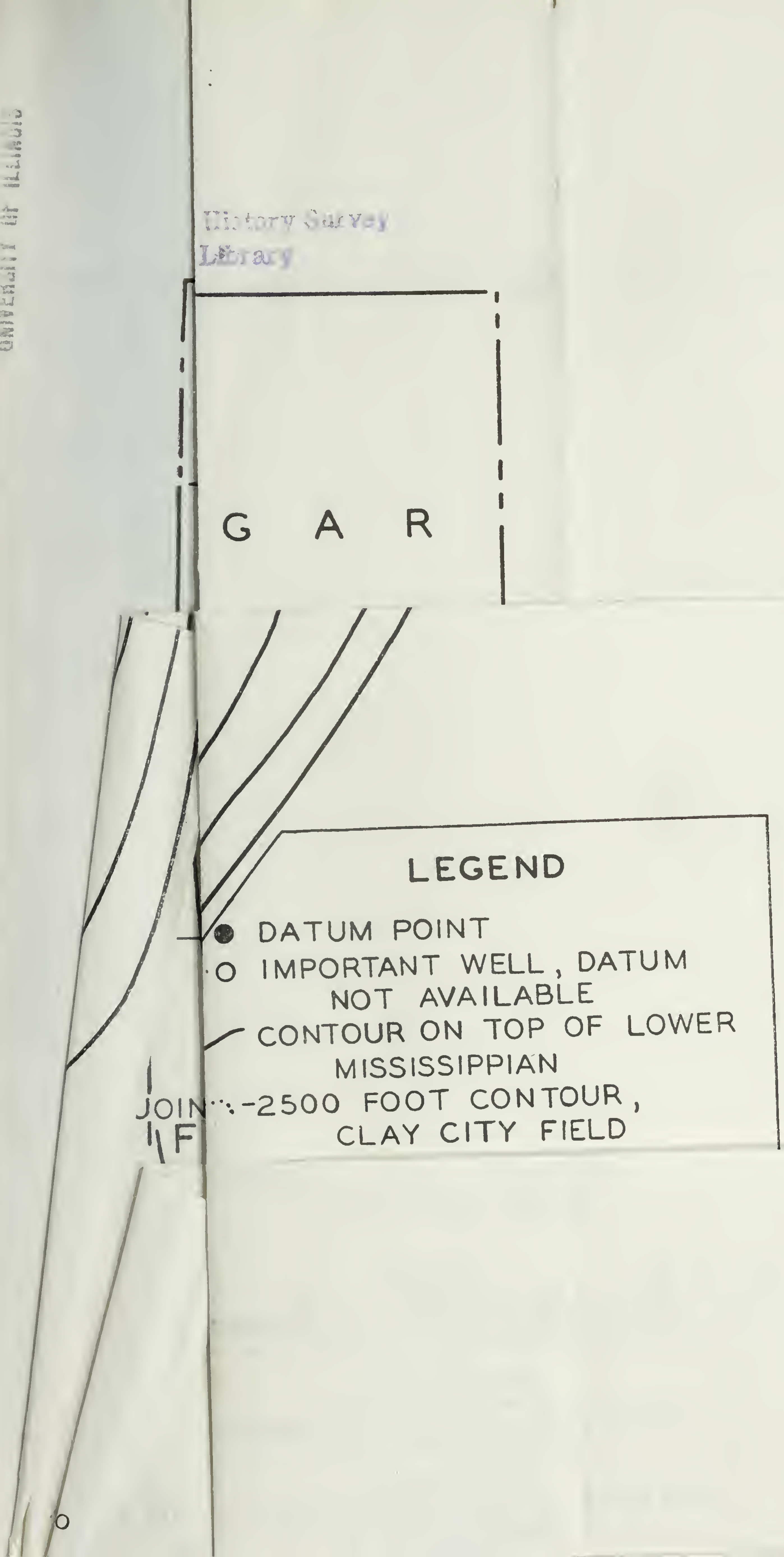
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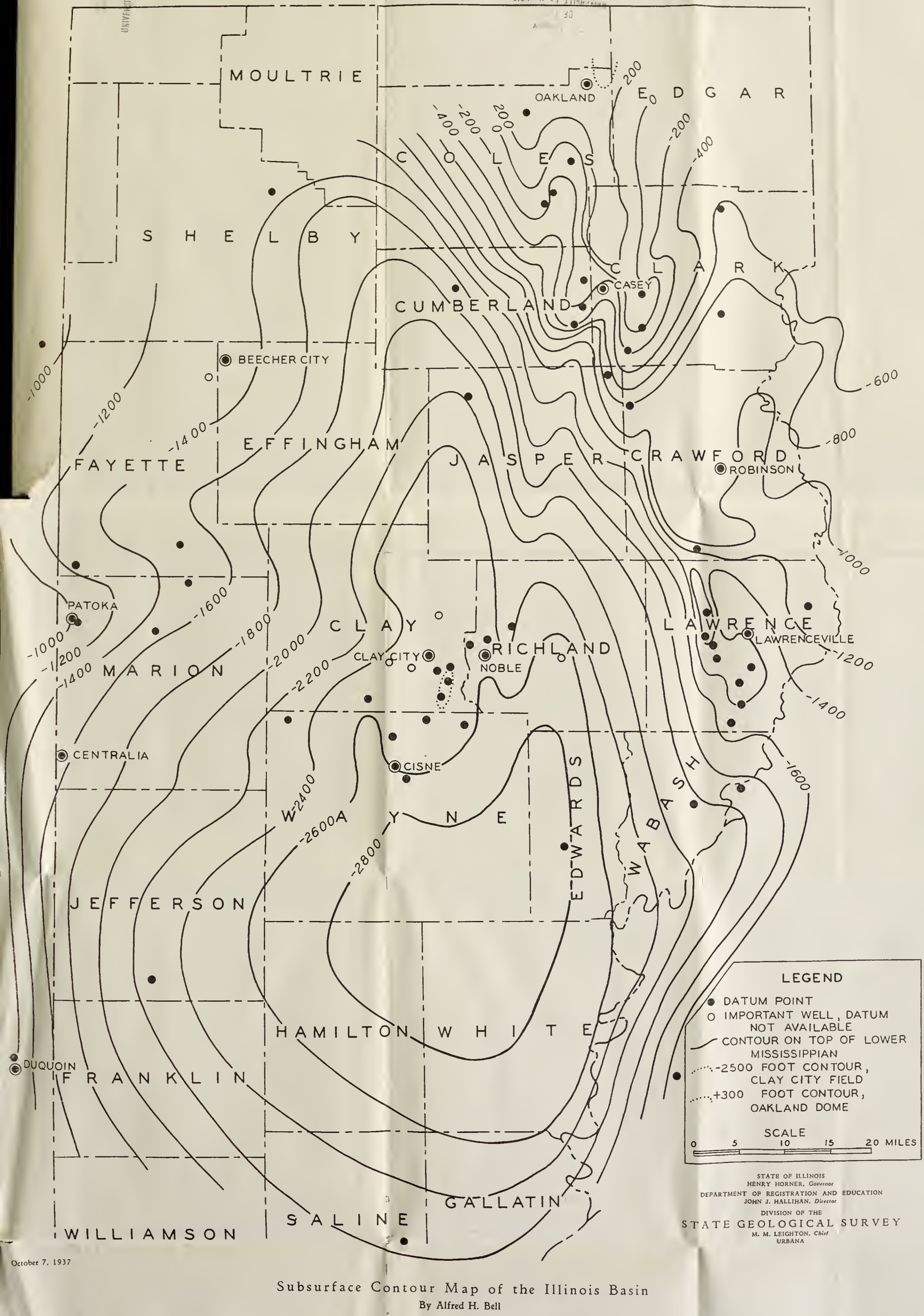

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October 7, 1937

Subsurface Contour Map of the Illinois Basin

By Alfred H. Bell

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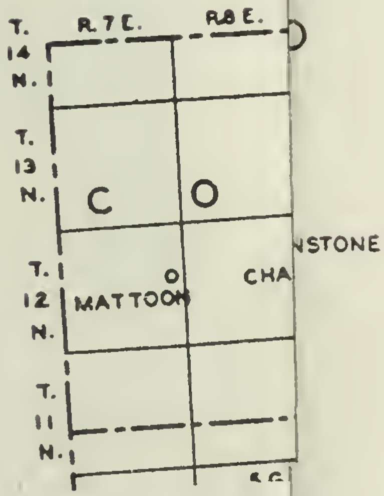
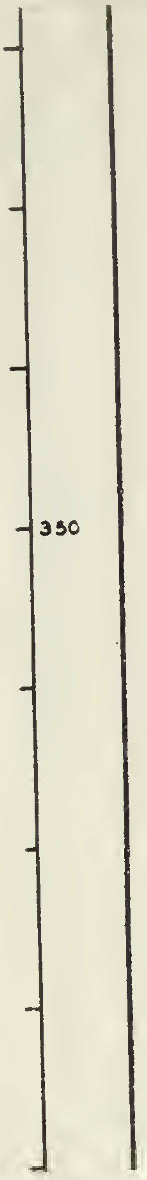
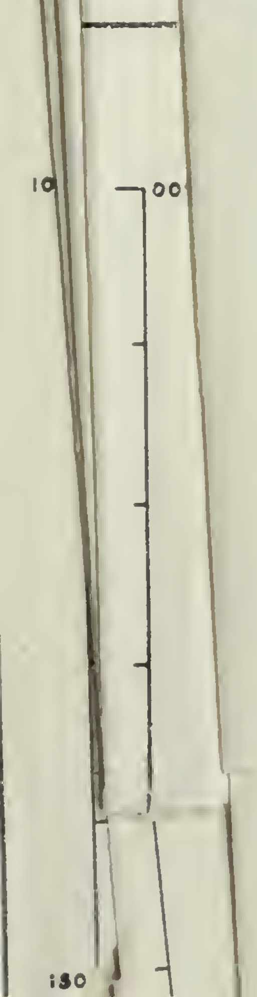
INVESTIGATIONS NO. 45—PLATE I





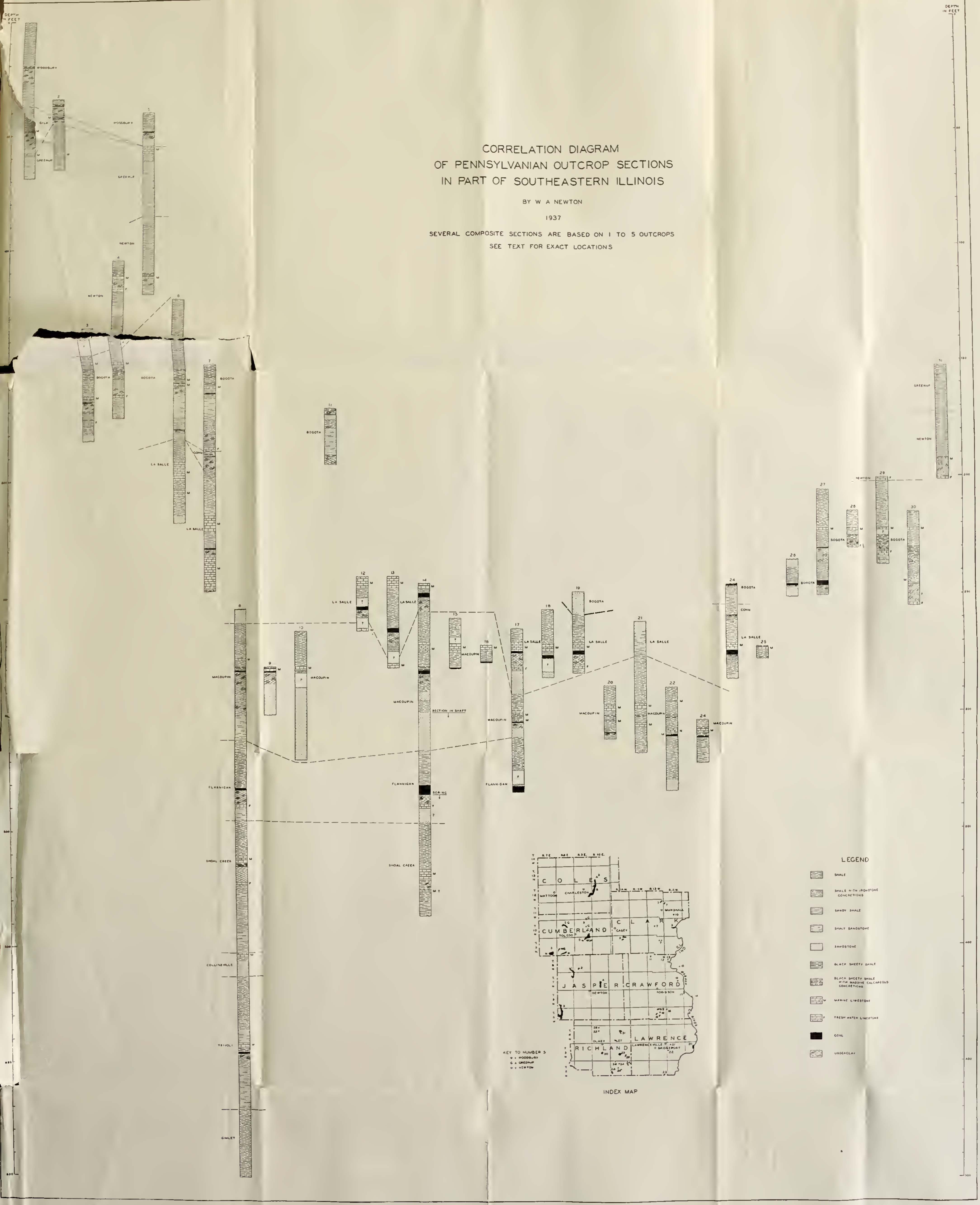


CORRELATION DIAGRAM OF PENNSYLVANIAN OUTCROP SECTIONS IN PART OF SOUTHEASTERN ILLINOIS

BY W A NEWTON

1937

SEVERAL COMPOSITE SECTIONS ARE BASED ON 1 TO 5 OUTCROPS
SEE TEXT FOR EXACT LOCATIONS



ERRATUM: On the above index map the township line between R. 11 E. and R. 14 W. through Jasper and Richland counties is omitted. R. 11 E. is only one section wide. See figure 2 for correct township lines.

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REPORT OF INVESTIGATIONS—NO. 45

STRATIGRAPHIC STUDIES OF PENNSYLVANIAN OUTCROPS IN PART OF SOUTHEASTERN ILLINOIS

BY

WILLIAM A. NEWTON and J. MARVIN WELLER

AUG. 26TH 1818

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